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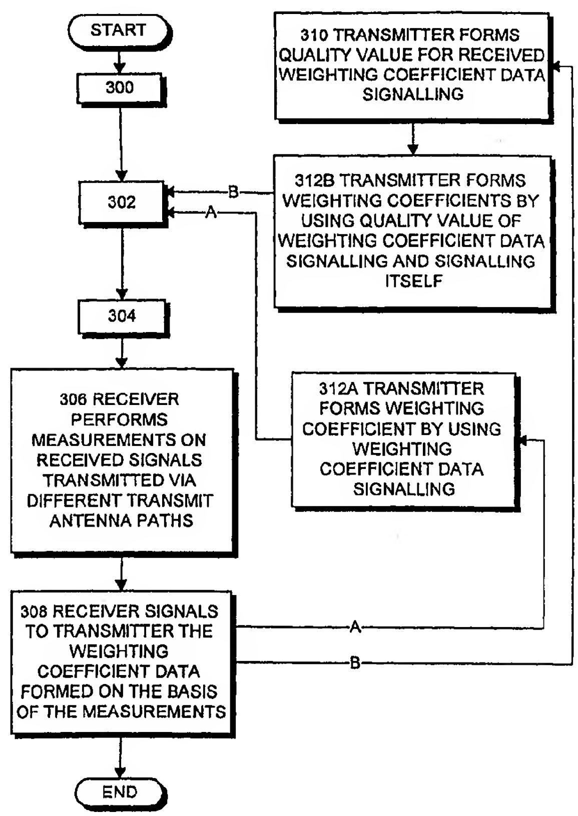
(54) Title: METHOD AND RADIO SYSTEM FOR DIGITAL SIGNAL TRANSMISSION

(57) Abstract

The invention relates to a method and a radio system for transmitting a digital signal. The method comprises the following steps: (300) the transmitter transmits at least a part of the signal via at least two different transmit antenna paths; (302) the transmitter weights the transmit power of the signals to be transmitted via the different transmit antenna paths with respect to one another by means of changeable weighting coefficients determined for each transmit antenna path; (304) the receiver receives the signal. In an embodiment, (306) the transmitter performs measurements on the received signals that were transmitted via the different transmit antenna paths; (308) the receiver signals to the transmitter the weighting coefficient data formed on the basis of the masurements; (312A) the transmitter forms weighting coefficients by means of the weighting coefficient data signalling. In another embodiment, (310) the transmitter forms a quality value for the weighting coefficient data signalling it has received; (312B) the transmitter forms weighting coefficients by means of the quality value of the weighting coefficient data signalling and the signalling itself.



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METHOD AND RADIO SYSTEM FOR DIGITAL SIGNAL TRANSMISSION

FIELD OF THE INVENTION

The invention relates to a method and a radio system for transmitting a digital signal in a radio system, particularly in a mobile system. More precisely, the invention relates to the use of transmit diversity.

BACKGROUND OF THE INVENTION

In mobile systems, signal fading over the radio path interferes with reliable transmission. The problem is aggravated in new systems where rather high data transfer rates are transmitted, in addition to speech, together with new services, such as data transmission, which require a very good bit error ratio.

A possible solution to the problem is the use of transmit diversity. This means that the base station transmits a signal to a user equipment by means of two or more different antennas. Therefore the multipath signal components which have propagated via different channels will not likely be disturbed by simultaneous fading.

In selective transmit diversity (STD), the base station transmits a signal to a user equipment by using at least two different antenna candidates. The user equipment measures the quality of the signal transmitted by each antenna candidate and selects the antenna that provides the best quality. The user equipment signals the identification data of the selected antenna to the base station, whereafter the network part of the mobile system guides the transmissions to the user equipment via the selected antenna. This kind of signalling method forms closed loop control. A problem with this method is that the user equipment must be able to reliably signal the identification data of the selected antenna to the network part. STD is described in *Transmit Diversity by Antenna Selection in CDMA Downlink* by Ari Hottinen and Risto Wichman (IEEE Fifth International Symposium on Spread Spectrum Techniques & Applications. IEEE ISSSTA '98 Proceedings. September 2-4, 1998, Sun City, South Africa), which is incorporated herein by reference.

Another manner of implementing transmit diversity is the use of Space-Time Transmit Diversity (STTD). The operating principle of STTD differs from STD in that in STTD a signal is transmitted continuously to a user equipment by means of at least two different antennas. The signals that are transmitted via separate antennas are different. There are two manners of

implementing the difference: space-time trellis codes and space-time block codes.

Space-time trellis codes are described in WO 97/41670, which is incorporated herein by reference. They provide both coding and diversity gain. The codes are formed by means of a trellis diagram, which describes with two symbols each possible state and branches to other states. When the initial state of the trellis is known, the bits to be coded can be indicated in the trellis diagram by means of symbols denoting transfers between different levels. The obtained symbols are thereafter distributed for transmission via different antennas.

In space-time block codes the bits to be coded are divided for example into two-bit sequences, which are formed into symbols to be transmitted, such that the symbol to be transmitted via the first antenna consists of the first bit and the complex conjugate of the second bit, and the symbol to be transmitted via the second antenna consists of the second bit and the complex conjugate of the first bit. The formation of space-time block codes is described in *Space-Time Coding for High Data Rate Wireless Communications* by A.R. Calderbank, Hamid Jafakhani, Ayman Naguib, Nambi Seshadri and Vahid Tarokh (Fifth Workshop on Smart Antennas in Wireless Mobile Communications. July 23-24, 1998, Stanford University), which is incorporated herein by reference.

In STTD, the transmit power of transmit antennas is constant or it can be controlled by means of closed loop control, wherein a user equipment measures the quality of the signals it has received, and based thereon, the network part adjusts the absolute transmit power of the signal it transmits via the antennas, such that the ratio of the transmit powers is always the same over each transmit antenna path utilizing transmit diversity. However, the arrangement can cause an unnecessarily great deal of interference to other users in the mobile system. This method also has the problem of reliability of signalling, in other words the user equipment must be able to reliably signal power control data to the network part.

BRIEF DESCRIPTION OF THE INVENTION

An object of the invention is to develop a method and equipment implementing the method so as to solve the aforementioned problems. This is achieved with the method described below, which is a method of transmitting a digital signal from a transmitter to a receiver in a radio system, the method

comprising: the transmitter transmitting at least a part of the signal via at least two different transmit antenna paths; the receiver receiving the signal. The transmit power of the signals to be transmitted via different transmit antenna paths is weighted with respect to one another in the transmitter by means of changeable weighting coefficients determined for each transmit antenna path.

The invention also relates to a radio system for transmitting a digital signal, the system comprising a transmitter for transmitting a signal; at least two transmit antenna paths that can be connected to the transmitter; a receiver for receiving the signal. The transmitter comprises changing means for changing the weighting coefficients determined for each transmit antenna path with respect to one another, and weighting means for weighting the transmit power of the signals to be transmitted via different transmit antenna paths by means of weighting coefficients that can be changed with respect to one another.

The preferred embodiments of the invention are disclosed in the dependent claims.

The invention is based on developing further the adjustment of transmit power such that each transmit antenna path used in the transmit diversity will be adjusted separately. However, the power levels of the transmit antenna paths are adjusted with respect to one another. This means that the adjustment is not the same for all the transmit antenna paths, nor is the adjustment performed mutually independently on each transmit antenna path.

The method and the system according to the invention provide several advantages. Errors in closed loop control, for example in signalling from a user equipment to a base station, do not significantly deteriorate the capacity of the system. In the prior art, a receiver blindly follows the antenna selection commands by the closed loop, which causes a random change of the transmit antenna due to erroneous commands. This weakens signal quality.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

Figures 1A and 1B show an example of a system according to the invention,

Figure 2A shows the operation of a transmitter and a receiver according to the invention,

Figure 2B shows spreading and modulation carried out in the transmitter,

Figure 3A is a flowchart of the basic method according to the invention,

Figure 3B is a flowchart of the preferred embodiments of the method according to the invention,

Figure 4 shows channels of the mobile system placed in a frame,

Figure 5 shows a preferred embodiment of the invention, and

Figure 6 shows another preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The invention can be used in radio systems where at least a part of a signal can be transmitted over at least two transmit antenna paths. A transmission channel can be formed by means of a time division, frequency division or code division multiple access method, for example. The invention also covers systems utilizing combinations of different multiple access methods. The examples describe the use of the invention in a universal mobile telecommunications system employing a direct sequence wideband code division multiple access method, without restricting the invention thereto, however.

The structure of a universal mobile telecommunications system will be described below with reference to Figures 1A and 1B. Figure 1B shows only the blocks that are essential for illustrating the invention, but it is evident to those skilled in the art that a conventional mobile system also includes other functions and structures which do not have to be described in greater detail herein. The main components of a mobile system are a core network CN, a UMTS terrestrial radio access network UTRAN and a user equipment UE. The interface between the CN and the UTRAN is called Iu, and the air interface between the UTRAN and the UE is called Uu.

The UTRAN consists of radio network subsystems RNS. The interface between RNSs is called Iur. An RNS consists of a radio network controller RNC and one or more nodes B. The interface between an RNC and node B is called Iub. The coverage area of node B, i.e. a cell, is denoted in Figure 1B by C.

The illustration in Figure 1A is extremely abstract, wherefore it is further clarified in Figure 1B by showing which parts of the GSM system and the UMTS approximately correspond to one another. It should be noted that

the mapping disclosed herein is not restrictive but only suggestive, since the responsibilities and functions of different parts of the UMTS are still under development.

Figure 1B shows packet transmission via the Internet 102 from a computer 100 that is connected to a mobile system to a portable computer 122 connected to a user equipment UE. The UE can be for example a fixedly positioned terminal equipment, an equipment placed in a vehicle or a portable hand-held device. The radio network infrastructure UTRAN consists of radio network subsystems RNS or base station systems. An RNS consists of a radio network controller RNC or a base station controller, and at least one node B or base station it controls.

The base station B comprises a multiplexer 114, transceivers 116 and a control unit 118, which controls the operation of the transceivers 116 and the multiplexer 114. The multiplexer 114 places traffic and control channels used by several transceivers 116 on the transmission connection Iub.

The transceivers 116 of the base station B are connected to an antenna unit 120, which implements a bidirectional radio connection Uu to the user equipment UE. The structure of the frames transmitted over the bidirectional radio connection Uu is accurately specified.

The base station controller RNC comprises a group switching field 110 and a control unit 112. The group switching field 110 is used to switch speech and data and to combine signalling circuits. The base station system consisting of the base station B and the base station controller RNC also comprises a transcoder 108. The division of operations between the base station controller RNC and the base station B and the physical structure of the elements may vary in different implementations. The base station B typically manages the implementation of the radio path as described above. The base station controller RNC typically controls the following matters: radio resource management, control of inter-cell handover, power control, timing and synchronization, and paging of user equipments.

The transcoder 108 is usually situated as close to a mobile services switching centre 106 as possible in order that speech can be transmitted in a mobile telephone system form between the transcoder 108 and the base station controller RNC, thus saving transmission capacity. The transcoder 108 adapts different digital speech coding forms used between a public switched

telephone network and a mobile telephone network to each other, such that it converts for example a 64 kbit/s fixed network form into some other (such as a 13 kbit/s) form of the cellular radio network, and vice versa. The required equipment is not described in greater detail herein. Suffice it to say that speech is the only type of data that is converted in a transcoder 122. The control unit 112 performs call control, mobility management, collection of statistical data, and signalling.

The core network CN consists of the infrastructure of the mobile telephone system outside the UTRAN. From the devices of the core network CN, Figure 1B shows the mobile services switching centre 106 and a gateway mobile services switching centre 104, which manages the connections from the mobile telephone system to the outside world, in this case to the Internet 102.

Figure 2B shows in more detail the spreading of a channel with a spreading code and the modulation of the channel. A channel bit stream arrives at block S/P from the left in the figure. In the block each two-bit sequence is converted from a serial form into a parallel form, which means that one bit is supplied to the I branch of the signal and the other bit is supplied to the Q branch. The I and Q branches of the signal are then multiplied by the same spreading code c_{ch}, thus spreading relatively narrowband information over a broad frequency band. Each connection Uu has its own spreading code, which enables the receiver to identify transmissions intended for it. The signal is thereafter scrambled by multiplying it by a scrambling code c_{scramb}, which is different for each user equipment and base station. The pulse form of the obtained signal is filtered by a filter p(t). Finally, the signal is modulated into a radio-frequency carrier by multiplying the different signal branches by a carrier. There is a phase shift of 90 degrees between the carriers of the different branches. The different branches are combined into a single carrier, which is ready for transmission to the radio path Uu, excluding possible filtrations and power amplifications. The modulation method described is quadrature phase shift keying (QPSK).

The maximum number of mutually orthogonal spreading codes that can be used simultaneously is typically 256 different codes. For example in the UMTS, with a carrier of 4.096 megachips, spreading factor 256 corresponds to a transfer rate of 32 kbit/s, and the corresponding highest transfer rate in practice is achieved with spreading factor 4, which gives a data transfer rate of

2048 kbit/s. The transfer rate on a channel thus varies in steps of 32, 64, 128, 256, 512, 1024 and 2048 kbit/s, and the spreading factor changes correspondingly as follows: 256, 128, 64, 32, 16, 8 and 4. The data transfer rate allocated to a user depends on the channel coding used. For example with 1/3 convolutional coding, the user data transfer rate is usually about one third of the channel data transfer rate. The spreading factor may indicate the length of the spreading code. For example the spreading code corresponding to spreading factor 1 is (1). Spreading factor 2 has two mutually orthogonal spreading codes: (1,1) and (1,-1). Further, spreading factor 4 has four mutually orthogonal spreading codes: below a higher-level spreading code (1,1) are spreading codes (1,1,1,1) and (1,1,-1,-1), and below another higher-level spreading code (1,-1) are spreading codes (1,-1,1,-1) and (1,-1,-1,1). Spreading codes on a particular level are usually mutually orthogonal, for example when a Walsh-Hadamard code set is used.

An example of a frame structure that can be used on a physical channel will be described with reference to Figure 4. Frames 440A, 440B, 440C, 440D are numbered consecutively from one to seventy-two, and they form a 720-millisecond superframe. The length of one frame 440C is 10 milliseconds. A frame 440C is divided into 16 slots 430A, 430B, 330C, 330D. The length of one slot 330C is 0.625 milliseconds. One slot 430C typically corresponds to one power control period, during which the power is adjusted for example by one decibel up or down.

Physical channels are divided into different types, including common physical channels and dedicated physical channels. Dedicated physical channels consist of dedicated physical data channels (DPDCH) 410 and dedicated physical control channels (DPCCH) 412. The DPDCHs 410 are used to carry data 406 generated in layer two of OSI (Open Systems Interconnection) and in the layers above it, i.e. dedicated control channels and dedicated traffic channels. The DPCCHs 412 carry control information generated in layer one of the OSI. The control information comprises: pilot bits 400 used in channel estimation, transmit power control commands (TPC) 402, and optionally a transport format indicator (TFI) 404. The transport format indicator 404 indicates to the receiver the current transfer rate for each uplink DPDCH.

As Figure 4 shows, the downlink DPDCHs 410 and DPCCHs 412 are time-multiplexed into the same slot 430C. In the uplink direction the

channels are transmitted in parallel so that they are IQ/code-multiplexed (I = in-phase, Q = quadrature) into each frame 440C and they are transmitted using dual-channel quadrature phase-shift keying (QPSK) modulation. If additional DPDCHs 410 are to be transmitted, they are code-multiplexed either into the I or the Q branch of the first channel pair.

Figure 2A shows a transmitter 200 according to the invention utilizing transmit diversity, and a receiver 220. Figure 2 shows a downlink situation where the transmitter is situated in a radio network subsystem RNS and the receiver in a user equipment UE.

Figure 2A shows only the basic functions of the radio transmitter 200. Different services to be conveyed in a physical channel include speech, data, moving or still video image, and system control channels, which are processed in a control part 208 of the radio transmitter. The figure only shows the processing of data. Different services require different source coding means, for example speech calls for a speech codec. However, the source coding means are not shown in Figure 2A for the sake of clarity.

Packets from the computer 100 arrive at the radio network subsystem RNS as shown in Figure 1B, and they are subjected to channel coding in a channel coder 202. The channel coding is typically convolutional coding or different modifications thereof, such as turbo coding. Channel coding also includes different block codes, such as cyclic redundancy check (CRC) and the Reed-Solomon code.

The space-time codes described above can also be used. In the case of space-time block codes, a signal can be first coded with for example Reed-Solomon coding and thereafter with space-time block coding. In space-time block coding the symbols to be transmitted, S_1 and S_2, are divided into two different transmit antenna paths such that signal $\begin{bmatrix} S_1 & -S_2^* \end{bmatrix}$ is transmitted via the first path 214B and signal $\begin{bmatrix} S_2 & S_1^* \end{bmatrix}$ is transmitted via the second path 214. Symbol * describes the complex conjugate of the signal. The signals formed in this manner are mutually orthogonal and can be transmitted with the same spreading code. Other possibilities of implementing orthogonality include the use of a specific spreading or channel code, a different transmission frequency or a different slot in transmission for each transmit antenna branch.

The signal received over path j at instant T is

$$r_j^1 = w_1\alpha_j^1 S_1 - w_2\alpha_j^2 S_2^* + n_j^1, \tag{1}$$

wherein a weighting coefficient for the transmit power of antenna *j* is denoted by w_j, and symbol a_j^i denotes Rayleigh fading of the j^{th} multipath of the i^{th} transmit antenna path in the receiver. Correspondingly, r_j^k represents the j^{th} multipath-propagated signal of the received signal, and n_j^k denotes additive white gaussian noise summed in the j^{th} multipath-propagated signal.

Correspondingly, a signal received at instant 2T is

$$r_j^2 = w_1\alpha_j^1 S_2 + w_2\alpha_j^2 S_1^* + n_j^2 \tag{2}$$

Denote below $\hat{\alpha} = w\alpha$, whereupon linear processing provides the following soft outputs for symbols S_1 and S_2 of the j^{th} path

$$r_j^1\hat{\alpha}_j^{1^*} + r_j^{2^*}\hat{\alpha}_j^2 = \left(\left|\hat{\alpha}_j^1\right|^2 + \left|\hat{\alpha}_j^2\right|^2\right)S_1 + n_j^1\hat{\alpha}_j^{1^*} + n_j^{2^*}\hat{\alpha}_j^2 \tag{3}$$

and

$$-r_j^{1^*}\hat{\alpha}_j^2 + r_j^2\hat{\alpha}_j^{1^*} = \left(\left|\hat{\alpha}_j^1\right|^2 + \left|\hat{\alpha}_j^2\right|^2\right)S_2 - n_j^{1^*}\hat{\alpha}_j^2 + n_j^2\hat{\alpha}_j^{1^*} \tag{4}$$

The soft outputs of all the multipaths can be combined to provide a net soft output for symbol S_1

$$\sum_{j=1}^{L} r_j^1\hat{\alpha}_j^{*1} + r_j^{2^*}\hat{\alpha}_j^2 , \tag{5}$$

wherein L is the total number of the received multipaths. Correspondingly, the net soft output for symbol S_2 is obtained as follows

$$\sum_{j=1}^{L} -r_j^{1^*}\hat{\alpha}_j^2 + r_j^2\hat{\alpha}_j^{1^*} \tag{6}$$

Interleaving is not shown in Figure 2A. The purpose of interleaving is to facilitate error correction. In the interleaving signal bits are mixed together in a certain manner, and therefore a momentary fade over the radio path does not necessarily make the transmitted information impossible to identify.

The signal is spread by a spreading code, scrambled by a scrambling code and modulated in a block 204, the operation of which was described in greater detail in connection with Figure 2B.

In a switching field 206 the signal is divided to different transmit antenna paths 214A, 214B, 214C. The control unit 208 controls the operation of the switching field 206. Transmit diversity is typically implemented such that the same signal is transmitted via at least two different transmit antenna paths 214A, 214B, 214C to the user equipment UE. In the example shown in Figure

2A, the transmit antenna diversity is implemented by two paths 214B, 214C. When the above-described space-time coding is used, the signal that is transmitted via the different antennas is not the same. In such a case it must be noted that the switching field divides the signals which have at least partly different contents to different transmit antenna paths 214B, 214C.

On each transmit antenna path 214B, 214C the signal is supplied to radio-frequency parts 210B, 210C, which comprise a power amplifier 212B, 212C. The radio-frequency parts 210B, 210C may also comprise filters that restrict the bandwidth. An analogue radio signal 240, 242 is thereafter transmitted via the antenna 214B, 214C to the radio path Uu.

The radio receiver 220 is typically a Rake receiver. An analogue radio-frequency signal 240, 242 is received from the radio path Uu by an antenna 222. The signal 240, 242 is supplied to radio-frequency parts 224 comprising a filter which blocks frequencies outside the desired frequency band. The signal is thereafter converted in a demodulator 226 into an intermediate frequency or directly to a baseband, and the converted signal is sampled and quantized.

Since the signal has arrived via several paths, the multipath-propagated signal components are preferably combined in a block 226 comprising several Rake fingers according to the prior art.

A rowing Rake finger searches for delays for each multipath-propagated signal component. After the delays have been located, each of the different Rake fingers is allocated to receive a specific multipath-propagated signal component. In the reception a received signal component is correlated by the spreading code used, which has been delayed by the delay located for the multipath in question. The different demodulated and despread multipath-propagated components of the same signal are combined to obtain a stronger signal.

The signal is thereafter supplied to a channel decoder 228, which decodes the channel coding used in the transmission, for example block coding and convolutional coding. Convolutional coding is preferably decoded by a Viterbi decoder. Space-time block coding is decoded by means of the linear processing described in connection with formulae 3, 4, 5 and 6. The obtained data that was originally transmitted is supplied to a computer 122 connected to the user equipment UE for further processing.

The method of transmitting a digital signal from the transmitter to the receiver in a radio system comprises the following steps described with reference to Figure 3A.

In block 300, the transmitter 200 transmits at least a part of the signal via at least two different transmit antenna paths 214B, 214C.

In block 302, the transmit power of the signals to be transmitted via the different transmit antenna paths 214B, 214C is weighted in the transmitter 200 with respect to one another by means of changeable weighting coefficients *w* determined specifically for each transmit antenna path 214B, 214C.

In block 304, the receiver receives the signal.

When a transmitter is being manufactured or the system is being specified or later, for example when the radio network is being set up, the weighting coefficients can be given default values used by the transmitter in the transmit antenna diversity.

Figure 3B shows how the weighting coefficients can be changed dynamically according to the channel conditions over the radio connection. Blocks 300, 302 and 304 are implemented similarly as in Figure 3A.

In block 306, the receiver 220 performs measurements on each received signal 240, 242 that was transmitted via a separate transmit antenna path 214B, 214C. The measurements relate to channel conditions, such as channel parameters, signal reception power, bit error ratio, signal/interference plus noise ratio (SINR), or any other manner in which the channel quality can be measured.

In block 308, the receiver 220 signals to the transmitter 200 the weighting coefficient data formed on the basis of the measurements carried out in block 306.

Next, there are two alternative ways to proceed, which are shown in Figure 3B as two different branches A and B stemming from block 308.

Branch A leads to block 312A, where the transmitter 200 forms weighting coefficients by means of the received signalling indicating the weighting coefficient data.

Branch B leads to block 310, where the transmitter 200 forms a quality value for the weighting coefficient data signalling it has received. In block 312B, the transmitter 200 forms weighting coefficients by means of the quality value for the weighting coefficient data signalling and the signalling

itself. A decision on the reliability of the signalling can be made by monitoring the quality value of the signalling: if the signal containing the signalling has propagated in a low-quality channel, it may not be sufficiently reliable to enable a good decision to be made for changing the weighting coefficients by means of the weighting coefficient data signalling. A quality value is formed similarly as described in connection with block 308.

A threshold value can be set for the reliability of signalling. When the quality value of signalling falls below a predetermined threshold value, the weighting coefficients are not changed. Correspondingly, when the quality value of signalling exceeds a predetermined threshold value, the weighting coefficients are changed. According to a special rule, when the quality value of signalling falls below a predetermined threshold value, the weighting coefficients are made equal over each transmit antenna path 214B, 214C used on the connection. The user equipment can also control the transmitter by changing, i.e. either increasing or decreasing, the reliability of the weighting coefficient signal on purpose. The reliability can be decreased for example by lowering the signal transmit power when the weighting coefficient signalling is carried out. In a CDMA system this can also be implemented by spreading the signalling data by a different spreading code than usually. In such a case the base station can either detect the spreading code with which the signalling was carried out or the signal can be despread without this data. In the latter case the received signal is not very reliable since the base station has used a different code to despread the signal than to spread it.

The frequency of the weighting coefficient data signalling is such that the weighting coefficient data can be transmitted in each 0.625-millisecond slot 330C shown in Figure 4. This means that the change frequency of the weighting coefficients is suitably equal to a typical power control period. The weighting coefficient data can be combined with the transmit power control command field 402 shown in Figure 4, or it can be placed in some other space reserved for control information in a DPCCH 412.

Weighting coefficient data signalling refers to the signalling the receiver 220 has transmitted to the transmitter 200 to be used in the adjustment of the weighting coefficients. It is evident to those skilled in the art that this signalling can be carried out in several different manners. A few possible manners will be described below, without restricting the invention thereto, however:

1. The weighting coefficient data indicates the transmit antenna path 214B, 214C via which the signal 240, 242 with the best quality value was transmitted. If there are only two transmit antenna paths, one bit is sufficient to convey this data. With more antenna paths more bits are correspondingly used.

2. The weighting coefficient data comprises differential information indicating how the ratios of the weighting coefficients of the transmit antenna paths 214B, 214C are changed differentially. This can be implemented for example with the following contents of the differential information: "transfer two units of the transmit power of the first transmit antenna path 214B to the second path 214C". Differential weighting is an example of a situation where weighting at instant *t* depends on the relative weighting used at instant *t-1*. It is also possible to use for example three groups of weighting coefficients: 1:{0.8 0.2}, 2:{0.5 0.5} and 3:{0.2 0,8}, wherein one shift is sufficient for changes 1<->2, 2<->3, but change 1<->3 requires two separate shifts.

3. The weighting coefficient data comprises at least one channel parameter measured by the receiver 220. An advantage of this embodiment is that a great deal of information can be signalled to the transmitter 200, if desired, and therefore the decision on the weighting coefficients can be made by the transmitter 200 which has received a sufficient amount of information. Part of the signal can be used to form transmit antenna paths and part for the weighting of signals of the transmit antenna paths.

4. The values of the weighting coefficients are determined in advance. The predetermined values of the weighting coefficients are divided into different groups, each of which comprises a particular weighting coefficient for each transmit antenna path 214B, 214C. In such a case the weighting coefficient data signalling comprises data about the group of weighting coefficients the receiver 220 wants to be used. With two transmit antenna paths 214B, 214C the groups can be for example as follows: {0.5, 0.5}, {0.8, 0.2} and {0.2, 0.8}. It is assumed that the combined transmit power is one. In the first group the transmit power of each transmit antenna path 214B, 214C is the same. In the second group, the first transmit antenna path 214B transmits at power 0.8 and the second transmit antenna path 214C at power 0.2. In the third group the first transmit antenna path 214B transmits at power 0.2 and the second path 214C at power 0.8. If the channel coding method used also enables transmission via only one transmit antenna path,

two more groups can be determined: {1, 0} and {0, 1}. This means that in the fourth group a signal is transmitted via only the first transmit antenna path 214B. Correspondingly, in the fifth group a signal is transmitted to the receiver 220 via only the second transmit antenna path 214C.

The receiver uses the channel coefficients of the received signal for signal detection. In order to enable this the signal conventionally comprises a predetermined, known pilot sequence by means of which the channel can be estimated if the channel coefficients change slowly. When weighting is used, the received channel coefficients change due to both the transmission path and the weighting of the transmitter. Therefore, the receiver 220 can operate better if it knows the weighting coefficients used by the transmitter 200. If great momentary changes are possible in the weighting coefficients used in the transmission, these coefficients are preferably signalled to the receiver 220 by means of identification bits 400 inserted in the transmitted signal. The operating principle of the bits is described in connection with Figure 4. Also, if the weighting coefficients have been grouped, the identification data of the group of coefficients used in the transmission is signalled to the receiver 220 by means of identification bits inserted in the transmitted signal. If the weighting coefficients are not to be signalled to the receiver 220, the receiver uses for example blind estimation methods to detect the weighting coefficients used. However, this is not even necessary. For example when the weighting coefficients are adjusted such that the relative power between two antennas is adjusted only by one decimal, the receiver 220 does not necessarily detect this adjustment but interprets it as a change in the channel conditions.

Other alternatives of signalling the used weighting coefficients to the receiver include modulation, spreading or coding of the signal specifically for each transmit antenna path.

The weighting coefficients can be determined in two different manners: either the user equipment UE in the radio system determines the weighting coefficients used by the network part of the radio system RNS in transmitting to the user equipment in question, or the network part RNS determines itself the coefficients it uses. Both alternatives provide advantages. If the user equipment UE makes the decision, the amount of the weighting coefficient data to be signalled can possibly be decreased. On the other hand, if the network part RNS makes the decision, it can possibly utilize data about the loading of the RNS that is not known to the user equipment UE. It is

naturally possible to use a combination of these two methods to determine the weighting coefficients.

An example of the network data is that the network part of the radio system RNS takes into account the loading of the power amplifier 212B, 212C of each transmit antenna path 214B, 214C when it makes the decision. The power amplifiers 212B, 212C have to be designed to withstand maximum power levels if the signals to be transmitted via the transmit antenna path 214B in question are adjusted to a high power level. The network part RNS can be programmed to observe a particular power limit for a power amplifier. In such a case the network part RNS locates for each radio connection such a combination of transmit antenna paths 214A, 214B, 214C that provides a sufficiently good quality of connection and that loads the power amplifiers 212A, 212B, 212C as evenly as possible.

The example described in connection with Figure 2A illustrates the use of the invention in a system where the transmit antenna paths 214A, 214B, 214C used are connected to a single base station B. However, the use of the weighting coefficients according to the invention is also suitable in the system shown in Figure 5, where a signal 240, 242 is transmitted via the transmitters 200B, 200C and transmit antenna paths 214B, 214C of at least two different base stations B1, B2. A typical situation is a soft handover where the base station controller RNC guides a simultaneous transmission to the user equipment UE for example via two different base stations B1, B2. In such a case the user equipment UE is situated in a border zone between two cells C1, C2. Particularly the methods described in connection with Figure 3B are suitable in such a situation.

Transmit antenna paths 214A, 214B, 214C refer to different ways of implementing an antenna arrangement used in transmission. A common antenna arrangement is the use of omnidirectional antennas. Sectorized base stations B can employ antennas covering a particular transmission sector. A base station B can utilize for example three 120° transmission sectors or even a higher number of at least substantially overlapping sectors. Another possible antenna arrangement is a structure implementing phasing. A phased antenna arrangement enables transmit antenna diversity with directional antenna beams, for example as shown in Figure 6. Two different transmit antenna paths 214B, 214C transmit a signal to a user equipment UE by means of a directional antenna beam 602B, 602C. Therefore the transmitter 200 must

comprise beam formers 600B, 600C. *An Adaptive Antenna Method for Improving Downlink Performance of CDMA Base Stations* by Juha Ylitalo and Marcos Katz (IEEE Fifth International Symposium of Spread Spectrum Techniques & Applications. IEEE ISSSTA '98 Proceedings. September 2-4, 1998, Sun City, South Africa), which is incorporated herein by reference, discloses the use of adaptive antennas. An essential feature of the invention is that the transmit antenna diversity and the use of weighting coefficients must be possible regardless of the antenna arrangement. When the space-time block coding is used, it is possible to for example determine a pattern for the transmit antenna path (the phases of the different antennas) by means of the signals which have arrived at the receiver, to select the two strongest signals, and to transmit part of the space-time block code simultaneously to these beams. By using an identifier for the beam or the transmit antenna path the user equipment can estimate weighting coefficients for the aforementioned two beams. Naturally, the complex phasing that determines a beam can be signalled to the transmitter by means of a closed loop, but this arrangement is only advantageous if the number of the transmit antennas is low. It is thus possible to separate the measurements and signalling determining the transmit antenna path and the weighting coefficients used for the selected transmit antenna paths. The space-time block coding is advantageous since due to the coding the signal is orthogonal in different beams, wherefore the base station can use the same spreading code in different beams.

The antenna phasing can be determined by means of the channel parameters signalled by the receiver.

The phasing of the transmission can be determined by means of signals arriving at the same antenna elements. This means that transmissions are sent to the same directions from which signals have been received on average. A direction is estimated for example over one slot (0.625 ms), frame (10 ms) or a longer interval of time.

In an embodiment transmissions are sent from at least one antenna element by means of at least two different phases or two different antenna beams, such that the signals that are transmitted with different phases have different pilot sequences, identification sequences, structures or different coding, preferably different parts of a space-time code, by means of which

- channel parameters of the beams are estimated,
- signals of the beams are combined,

- weighting coefficient information of the beams is calculated and signalled to the transmitter.

In the radio system of Figure 2A, the invention requires that the transmitter 200 comprises changing means 208 for changing the weighting coefficients determined for each transmit antenna path 214B, 214C with respect to one another. The transmitter also comprises weighting means 208, 212B, 212C for weighting the transmit power of the signals 240, 242 to be transmitted via the different transmit antenna paths 214B, 214C by means of weighting coefficients that can be changed with respect to one another. The weighting means consist of power amplifiers 212A, 212B, 212C and the control logic thereof.

The invention is preferably implemented by means of software, wherefore the transmitter 200 comprises a control unit 208 where the changing means 208 and the control logic for the weighting means are implemented by software. The invention can naturally also be implemented by means of integrated circuits providing the required functions. The invention also requires restricted changes in the software of the control units controlling the operation of the base station controller RNC, the base station B and the user equipment UE.

The receiver 220 comprises means 230 for performing measurements on the received signal transmitted via each different transmit antenna path, and means 230, 232 for signalling to the transmitter 200 the weighting coefficient data formed on the basis of the measurements. The measuring means 230 are prior art devices. Similarly, the signalling means 230, 232 are known, i.e. in practice they consist of the signalling software and the transmitter of the user equipment UE. The weighting coefficient data signalling is transmitted in the form of a radio signal 250 by a transmit antenna 234.

The transmitter 200 comprises means 216 for receiving the weighting coefficient data signalling, and the changing means 208 form the weighting coefficients by means of the signalling. The reception means 216 consist of the radio receiver 216 with the antennas 218 and the signalling software. The changing means 208 are preferably implemented by software.

The transmitter 200 comprises means 208, 216 for forming a quality value for the weighting coefficient data signalling it has received, and the changing means 208 form weighting coefficients by means of the quality value

of the signalling and the signalling itself. The means for forming the quality value are previously known.

The transmitter 200 comprises means 208 for signalling to the receiver the weighting coefficients or the identification data of the group of weighting coefficients used in the transmission by means of pilot or identification bits inserted in the transmitted signal 240, 242. This concerns accurately restricted changes made in the signalling software.

The user equipment UE can comprise means 230 for determining the weighting coefficients used by the network part of the radio system when transmitting to the user equipment UE in question. This is a decision-making logic preferably implemented by software, utilizing the rules described above in connection with the method.

The network part RNS can comprise decision-making means 208 for determining the weighting coefficients used in the transmission. This is preferably a decision-making logic implemented by software, utilizing the rules described above in connection with the method.

Even though the invention is described above with reference to an example according to the accompanying drawings, it is clear that the invention is not restricted thereto but it can be modified in several ways within the scope of the inventive idea disclosed in the appended claims.

CLAIMS

1. A method of transmitting a digital signal from a transmitter to a receiver in a radio system, the method comprising:

(300) the transmitter transmitting at least a part of the signal via at least two different transmit antenna paths;

(304) the receiver receiving the signal;

characterized in that

(302) the transmit power of the signals to be transmitted via different transmit antenna paths is weighted with respect to one another in the transmitter by means of changeable weighting coefficients determined for each transmit antenna path.

2. A method according to claim 1, **characterized** in that

(306) the receiver performs measurements on the received signals that were transmitted via the different transmit antenna paths;

(308) the receiver signals to the transmitter the weighting coefficient data formed on the basis of the measurements;

(312A) the transmitter forms weighting coefficients by means of the weighting coefficient data signalling.

3. A method according to claim 2, **characterized** in that

(310) the transmitter forms a quality value for the weighting coefficient data signalling it has received;

(312B) the transmitter forms weighting coefficients by means of the quality value of the weighting coefficient data signalling and the signalling itself.

4. A method according to claim 2, **characterized** in that the values of the weighting coefficients are predetermined, and the predetermined values of the weighting coefficients are divided into different groups, each of which has a particular weighting coefficient for each transmit antenna path, the weighting coefficient data signalling comprising information about which group of weighting coefficients the receiver wants to be used.

5. A method according to claim 2, **characterized** in that the weighting coefficient data comprises information about the transmit antenna path via which the signal with the best quality value was transmitted.

6. A method according to claim 2, **characterized** in that the weighting coefficient data comprises differential information indicating how the

ratios of the weighting coefficients for the transmit antenna paths are changed differentially.

7. A method according to claim 2, **characterized** in that the weighting coefficient data comprises at least one channel parameter measured by the receiver.

8. A method according to claim 2, **characterized** in that the transmit antenna paths are connected to at least two different base stations of a network part in the radio system.

9. A method according to claim 1, **characterized** in that the weighting coefficients used in the transmission are signalled to the receiver.

10. A method according to claim 9, **characterized** in that the weighting coefficients are signalled to the receiver by means of an identification sequence which is inserted in the transmitted signal and which varies depending on the weighting of the signal.

11. A method according to claim 9, **characterized** in that the weighting coefficients are signalled to the receiver by means of modulation, spreading or coding of the signal specifically for each transmit antenna path.

12. A method according to claim 4, **characterized** in that identification data for the group of weighting coefficients used in the transmission is signalled to the receiver by means of identification bits inserted in the transmitted signal.

13. A method according to claim 3, **characterized** in that when the quality value for signalling falls below a predetermined threshold value, the weighting coefficients are not changed.

14. A method according to claim 3, **characterized** in that when the quality value for signalling falls below a predetermined threshold value, the weighting coefficients are set to an equal value over each transmit antenna path.

15. A method according to claim 3, **characterized** in that when the quality value for signalling exceeds a predetermined threshold value, the weighting coefficients are changed.

16. A method according to claim 1, **characterized** in that signals to be transmitted via two different transmit antenna paths are as mutually orthogonal as possible.

17. A method according to claim 16, **characterized** in that the orthogonality is implemented by using a different spreading or channel code for each transmit antenna path.

18. A method according to claim 16, **characterized** in that the orthogonality is implemented by using a different transmission frequency for each transmit antenna path.

19. A method according to claim 16, **characterized** in that the orthogonality is implemented by using a different slot for each transmit antenna path.

20. A method according to claim 1, **characterized** in that the signal is coded in order to minimize transmission errors in the transmission channel.

21. A method according to claim 20, **characterized** in that the coding is space-time coding.

22. A method according to claim 21, **characterized** in that the space-time coding is space-time block coding.

23. A method according to claim 21, **characterized** in that the space-time coding is space-time trellis coding.

24. A method according to claim 1, **characterized** in that the transmit antenna paths are connected to one base station of the network part in the radio system.

25. A method according to claim 1, **characterized** in that the transmitter is situated in a radio network subsystem of the radio system network part, and the receiver is situated in a user equipment of the radio system.

26. A method according to claim 1, **characterized** in that a user equipment of the radio system determines the weighting coefficients used by the network part of the radio system in transmitting to the user equipment in question.

27. A method according to claim 1, **characterized** in that the network part of the radio system determines itself the weighting coefficients it uses in transmission.

28. A method according to claim 27, **characterized** in that the network part of the radio system takes into account the loading of each power amplifier over the transmit antenna path when it makes the decision.

29. A method according to claim 1, **characterized** in that a transmit antenna path is implemented by means of an antenna structure that provides phasing.

30. A method according to claim 29, **characterized** in that the phasing is determined by means of channel parameters signalled by the receiver.

31. A method according to claim 29, **characterized** in that the phasing of transmission is determined by means of signals that have arrived at the same antenna elements.

32. A method according to claim 29, **characterized** in that transmissions are sent from at least one antenna element with at least two different phases or antenna beams, such that signals to be transmitted with different phases have different pilot sequences, identification sequences, structures or different coding, preferably different parts of a space-time code, by means of which

- beam channel parameters are estimated,
- beam signals are combined,
- weighting coefficient information for the beams is calculated and signalled to the transmitter.

33. A radio system for transmitting a digital signal, comprising

a transmitter (200) for transmitting a signal (240, 242);

at least two transmit antenna paths (214B, 214C) that can be connected to the transmitter (200);

a receiver (220) for receiving the signal (240, 242);

characterized in that

the transmitter (200) comprises

changing means (208) for changing the weighting coefficients determined for each transmit antenna path (214B, 214C) with respect to one another, and

weighting means (208, 212B, 212C) for weighting the transmit power of the signals (240, 242) to be transmitted via different transmit antenna paths (214B, 214C) by means of weighting coefficients that can be changed with respect to one another.

34. A radio system according to claim 33, **characterized** in that

the receiver (220) comprises means (230) for performing measurements on the received signals that were transmitted via the different transmit antenna paths, and means (230, 232) for signalling to the transmitter (200) the weighting coefficient data formed on the basis of the measurements;

the transmitter comprises means (216) for receiving the weighting coefficient data signalling, and the changing means (208) form weighting coefficients by means of the weighting coefficient data signalling.

35. A radio system according to claim 34, **characterized** in that the transmitter (200) comprises means (208, 216) for forming a quality value for the weighting coefficient data signalling it has received, and the changing means (208) form weighting coefficients by means of the quality value of the weighting coefficient data signalling and the signalling itself.

36. A radio system according to claim 34, **characterized** in that the values of the weighting coefficients are predetermined, and the predetermined values of the weighting coefficients are divided into different groups, each of which has a particular weighting coefficient determined for each transmit antenna path (214B, 214C), the weighting coefficient data signalling comprising information about which group of weighting coefficients the receiver (220) wants to be used.

37. A radio system according to claim 34, **characterized** in that the weighting coefficient data comprises information about the transmit antenna path (214B, 214C) via which the signal (240, 242) with the best quality value was transmitted.

38. A radio system according to claim 34, **characterized** in that the weighting coefficient data comprises differential information indicating how the ratios of the weighting coefficients for the transmit antenna paths (214B, 214C) are changed differentially.

39. A radio system according to claim 34, **characterized** in that the weighting coefficient data comprises at least one channel parameter measured by the receiver (220).

40. A radio system according to claim 34, **characterized** in that the transmit antenna paths (214B, 214C) are connected to at least two different base stations of a network part in the radio system.

41. A radio system according to claim 33, **characterized** in that the transmitter (200) comprises means (208) for signalling the weighting

coefficients used in the transmission to the receiver (220) by means of pilot bits inserted in the transmitted signal (240, 242).

42. A radio system according to claim 36, **characterized** in that the transmitter (200) comprises means (208) for signalling to the receiver identification data for the group of weighting coefficients used in the transmission by means of pilot bits inserted in the transmitted signal (240, 242).

43. A radio system according to claim 35, **characterized** in that when the quality value for signalling falls below a predetermined threshold value, the changing means (208) do not change the weighting coefficients.

44. A radio system according to claim 35, **characterized** in that when the quality value for signalling falls below a predetermined threshold value, the changing means (208) set the weighting coefficients to an equal value over each transmit antenna path (214B, 214C).

45. A radio system according to claim 35, **characterized** in that when the quality value for signalling exceeds a predetermined threshold value, the changing means (208) change the weighting coefficients.

46. A radio system according to claim 33, **characterized** in that signals to be transmitted via two different transmit antenna paths (214B, 214C) are as mutually orthogonal as possible.

47. A radio system according to claim 33, **characterized** in that the transmitter (200) comprises means (202) for coding the signal in order to minimize transmission errors in the transmission channel.

48. A radio system according to claim 47, **characterized** in that the coding is space-time coding.

49. A radio system according to claim 48, **characterized** in that the space-time coding is space-time block coding.

50. A radio system according to claim 48, **characterized** in that the space-time coding is space-time trellis coding.

51. A radio system according to claim 33, **characterized** in that the transmit antenna paths (214B, 214C) are connected to one base station of the network part of the radio system.

52. A radio system according to claim 33, **characterized** in that the transmitter (200) is situated in a radio network subsystem (RNS) of the radio system network part, and the receiver (220) is situated in a user equipment (UE) of the radio system.

53. A radio system according to claim 33, **characterized** in that the user equipment (UE) of the radio system comprises means (230) for determining the weighting coefficients used by the network part of the radio system in transmitting to the user equipment (UE) in question.

54. A radio system according to claim 33, **characterized** in that the network part of the radio system comprises decision-making means (208) for determining the weighting coefficients it uses in transmission.

55. A radio system according to claim 54, **characterized** in that the decision-making means (208) utilize data about the loading of a power amplifier (212B, 212C) of each transmit antenna path (214B, 214C) when they make a decision.

56. A radio system according to claim 33, **characterized** in that a transmit antenna path (214B, 214C) is implemented by means of an antenna structure that provides phasing.

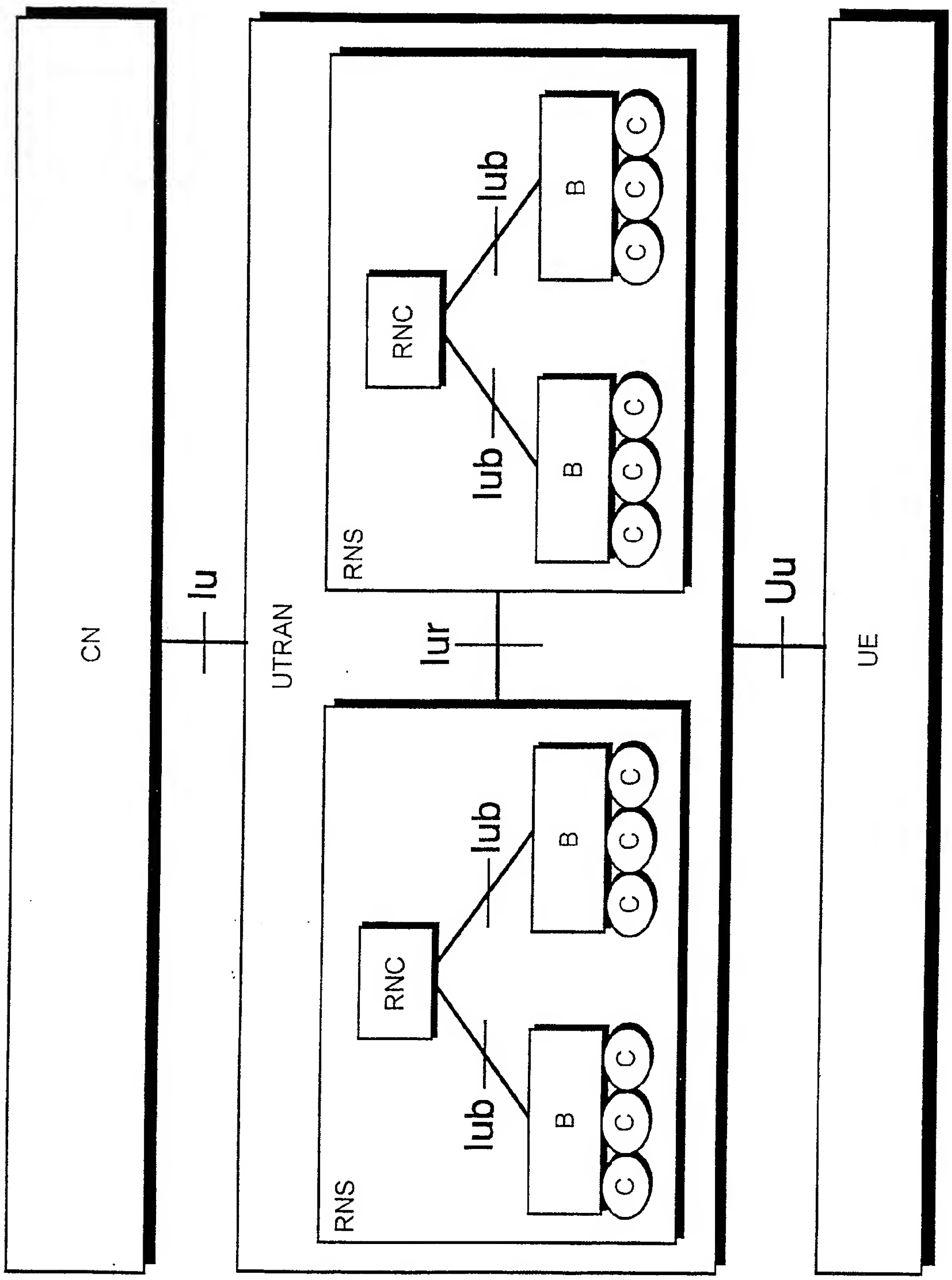

CN
Iu
UTRAN
RNS
RNC
Iub
Iub
B
B
C C C
C C C
Iur
RNS
RNC
Iub
Iub
B
B
C C C
C C C
Uu
UE

Fig 1A

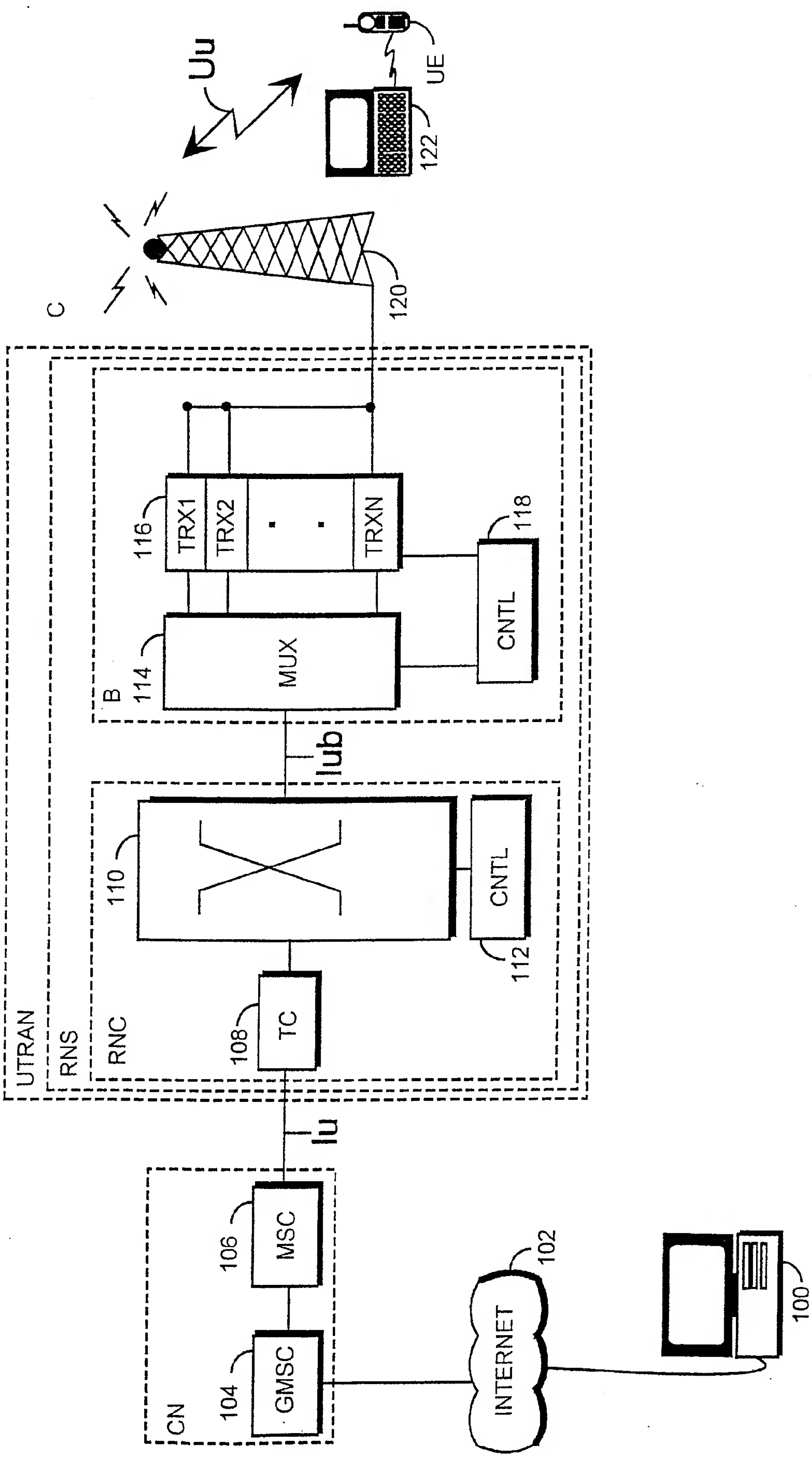
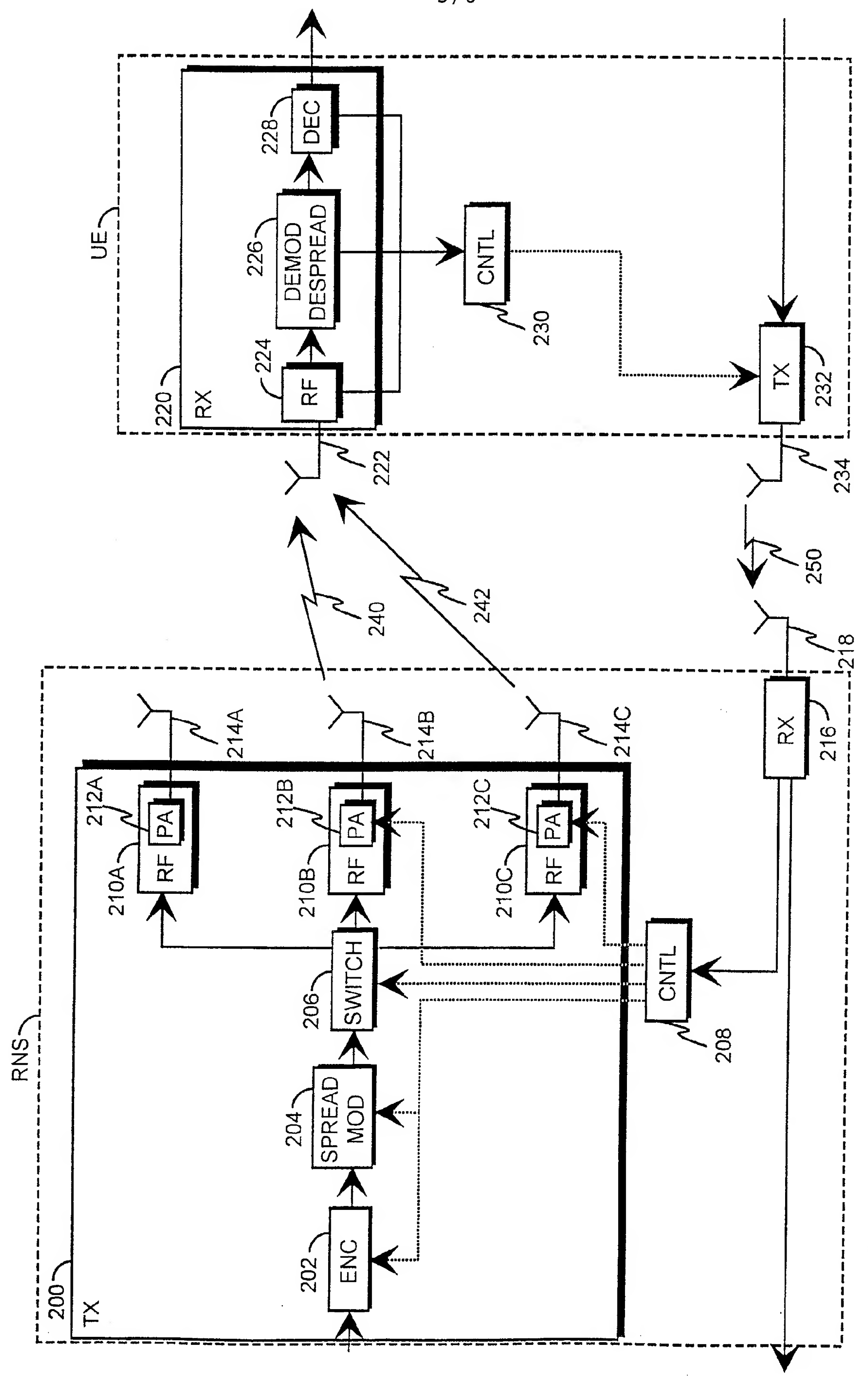

CN
GMSC
104
MSC
106
INTERNET
102
100
Iu
UTRAN
RNS
RNC
TC
108
110
CNTL
112
Iub
B
114
MUX
CNTL
118
TRX1
TRX2
TRXN
116
120
C
Uu
122
UE

Fig 1B


UE
RX
220
RF
224
DEMOD DESPREAD
226
DEC
228
CNTL
230
TX
232
222
234
250
240
242
218
RNS
TX
200
ENC
202
SPREAD MOD
204
SWITCH
206
CNTL
208
RF
210A
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212C
214A
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214C
RX
216

Fig 2A

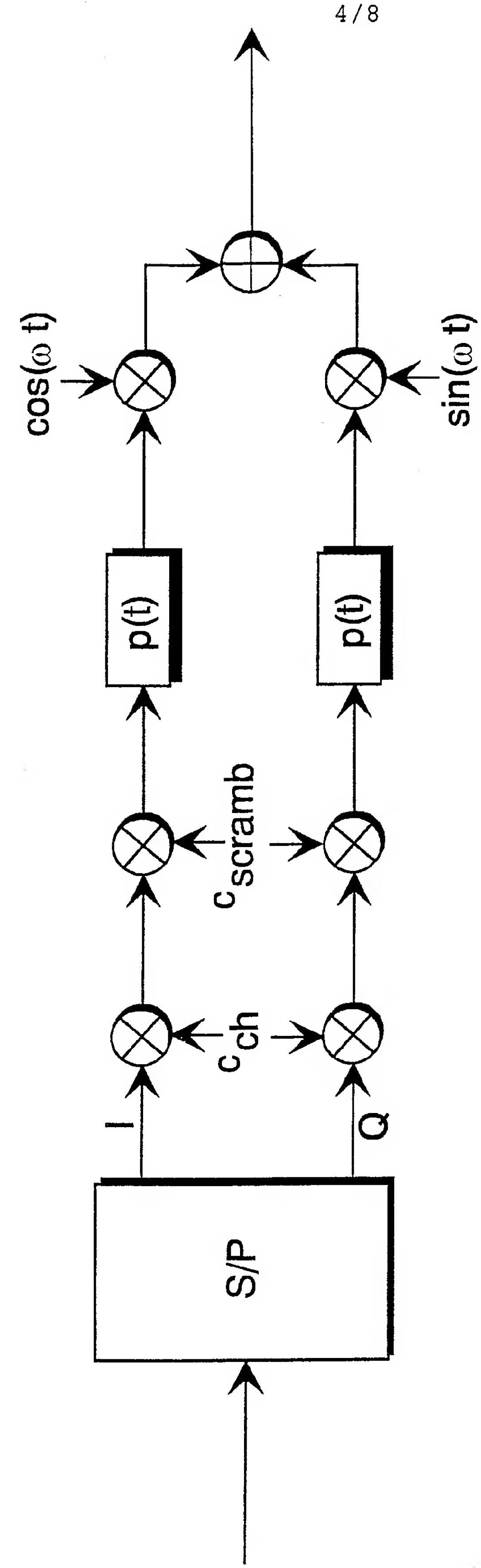

Fig 2B

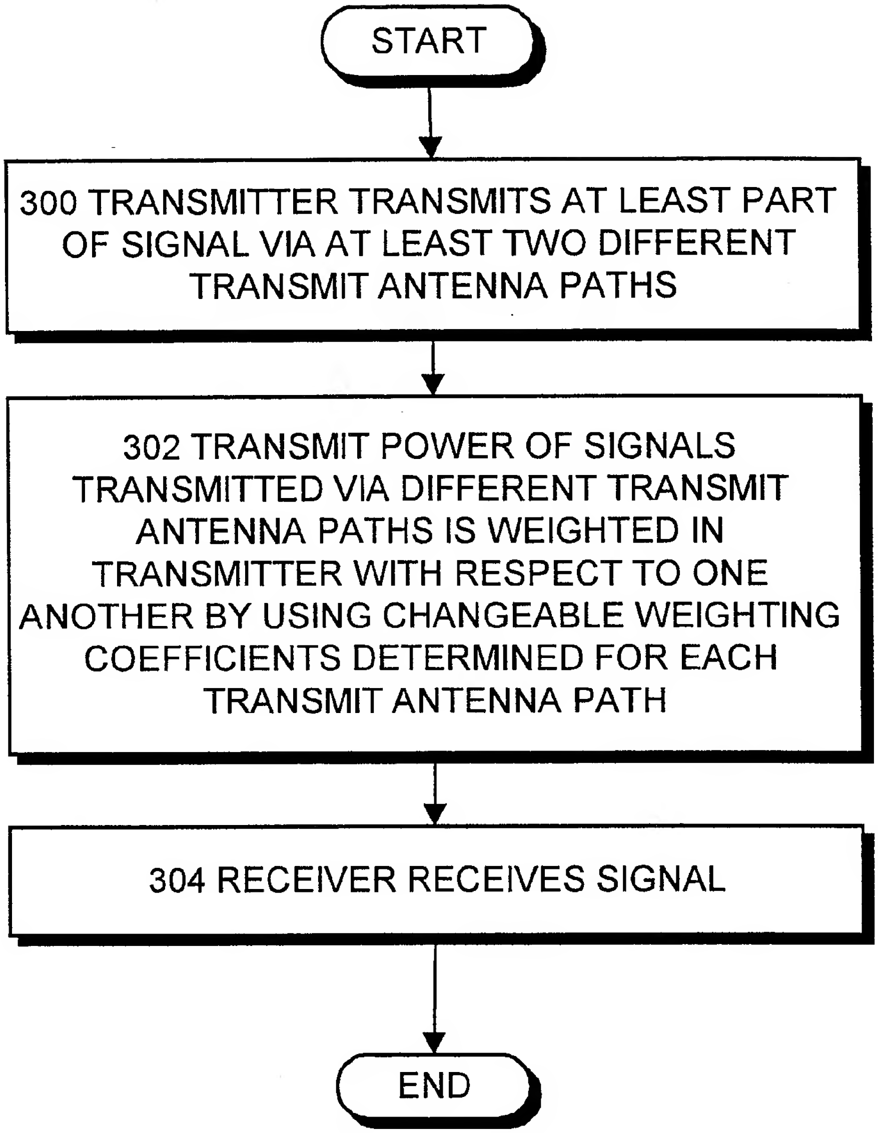
START
300 TRANSMITTER TRANSMITS AT LEAST PART OF SIGNAL VIA AT LEAST TWO DIFFERENT TRANSMIT ANTENNA PATHS
302 TRANSMIT POWER OF SIGNALS TRANSMITTED VIA DIFFERENT TRANSMIT ANTENNA PATHS IS WEIGHTED IN TRANSMITTER WITH RESPECT TO ONE ANOTHER BY USING CHANGEABLE WEIGHTING COEFFICIENTS DETERMINED FOR EACH TRANSMIT ANTENNA PATH
304 RECEIVER RECEIVES SIGNAL
END

Fig 3A

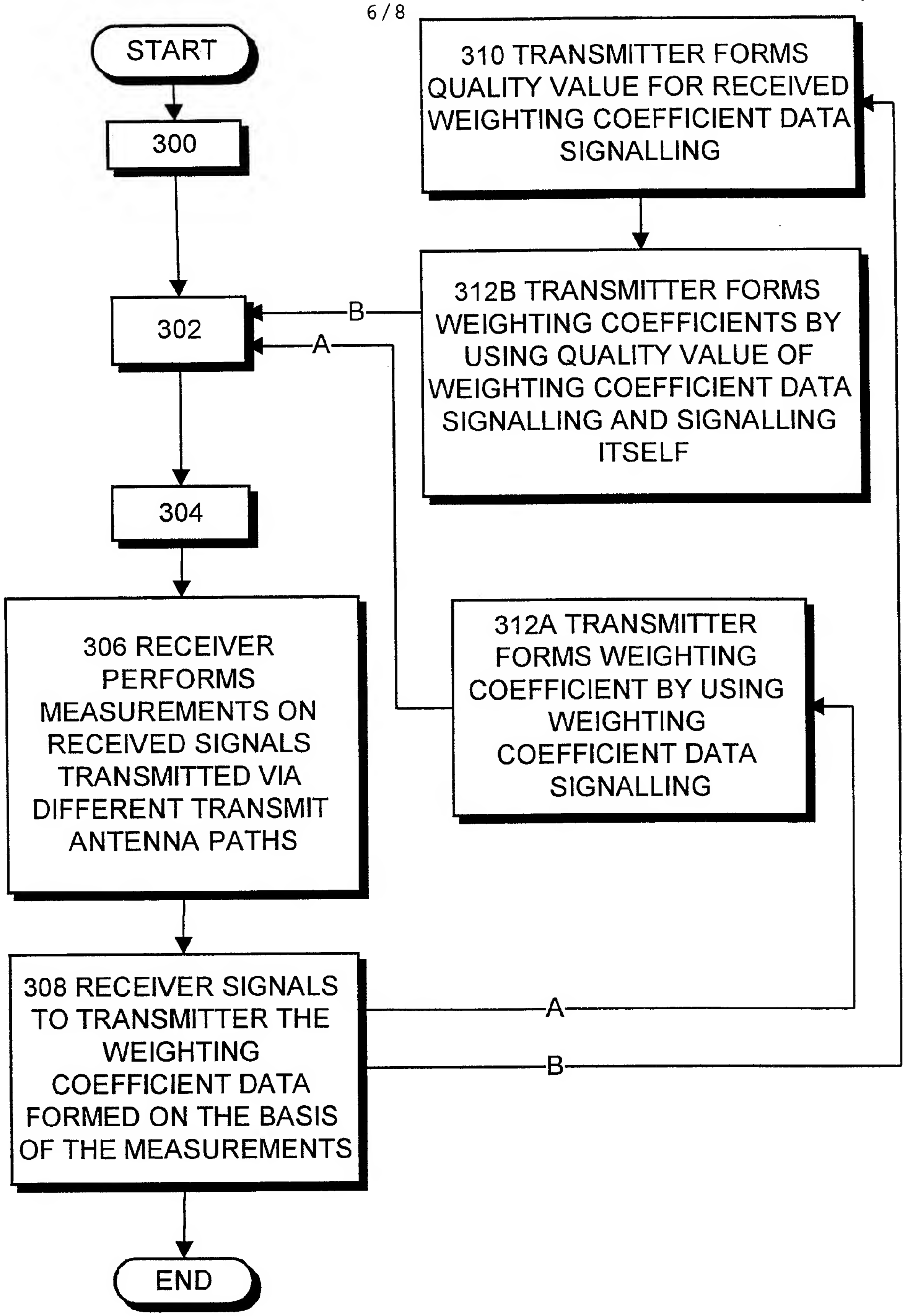
START
300
302
304
306 RECEIVER PERFORMS MEASUREMENTS ON RECEIVED SIGNALS TRANSMITTED VIA DIFFERENT TRANSMIT ANTENNA PATHS
308 RECEIVER SIGNALS TO TRANSMITTER THE WEIGHTING COEFFICIENT DATA FORMED ON THE BASIS OF THE MEASUREMENTS
END
310 TRANSMITTER FORMS QUALITY VALUE FOR RECEIVED WEIGHTING COEFFICIENT DATA SIGNALLING
312B TRANSMITTER FORMS WEIGHTING COEFFICIENTS BY USING QUALITY VALUE OF WEIGHTING COEFFICIENT DATA SIGNALLING AND SIGNALLING ITSELF
312A TRANSMITTER FORMS WEIGHTING COEFFICIENT BY USING WEIGHTING COEFFICIENT DATA SIGNALLING
A
B
A
B

Fig 3B

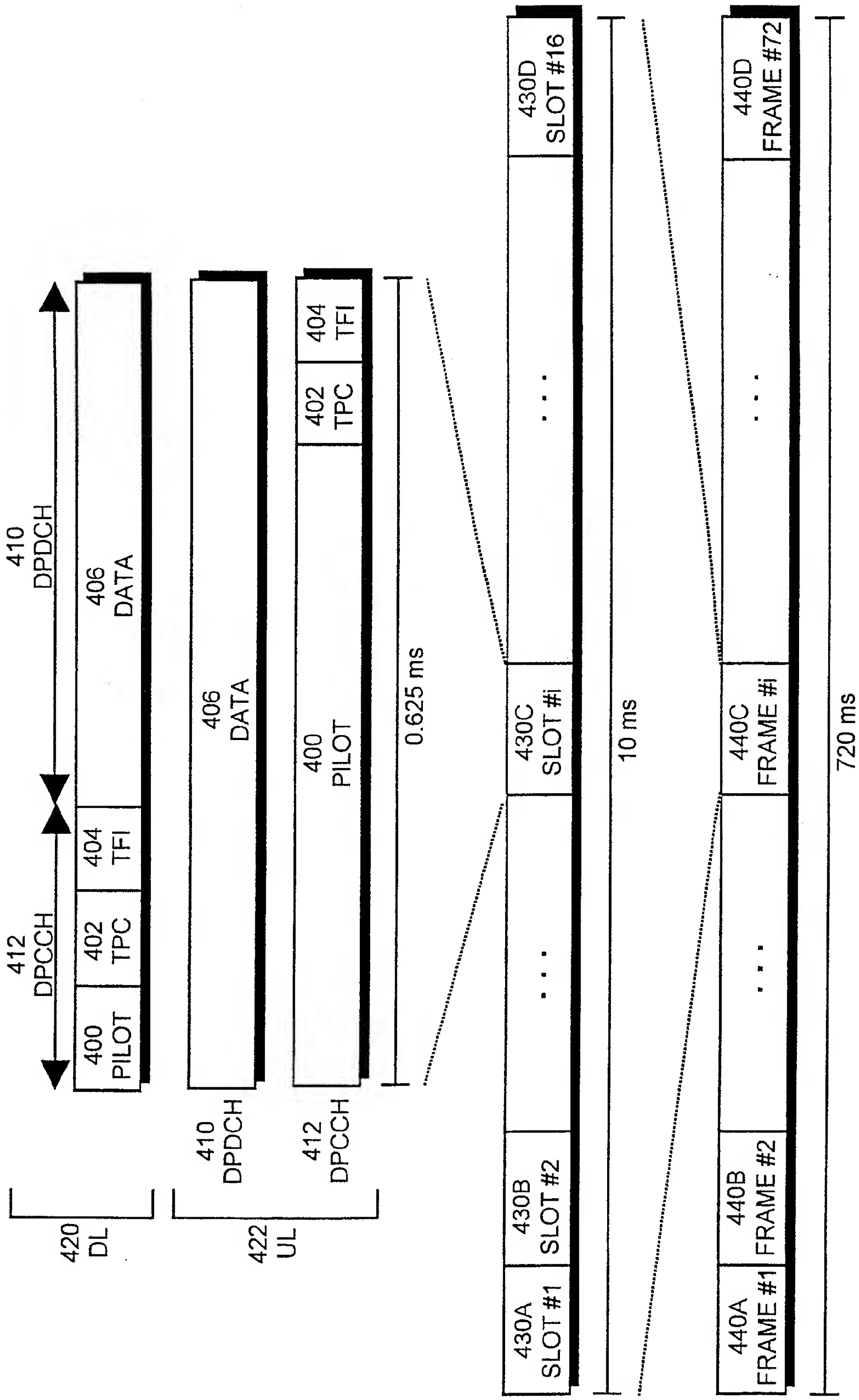
420
DL
410
DPDCH
412
DPCCH
400
PILOT
402
TPC
404
TFI
406
DATA
422
UL
410
DPDCH
406
DATA
412
DPCCH
400
PILOT
402
TPC
404
TFI
0.625 ms
430A
SLOT #1
430B
SLOT #2
430C
SLOT #i
430D
SLOT #16
10 ms
440A
FRAME #1
440B
FRAME #2
440C
FRAME #i
440D
FRAME #72
720 ms

Fig 4

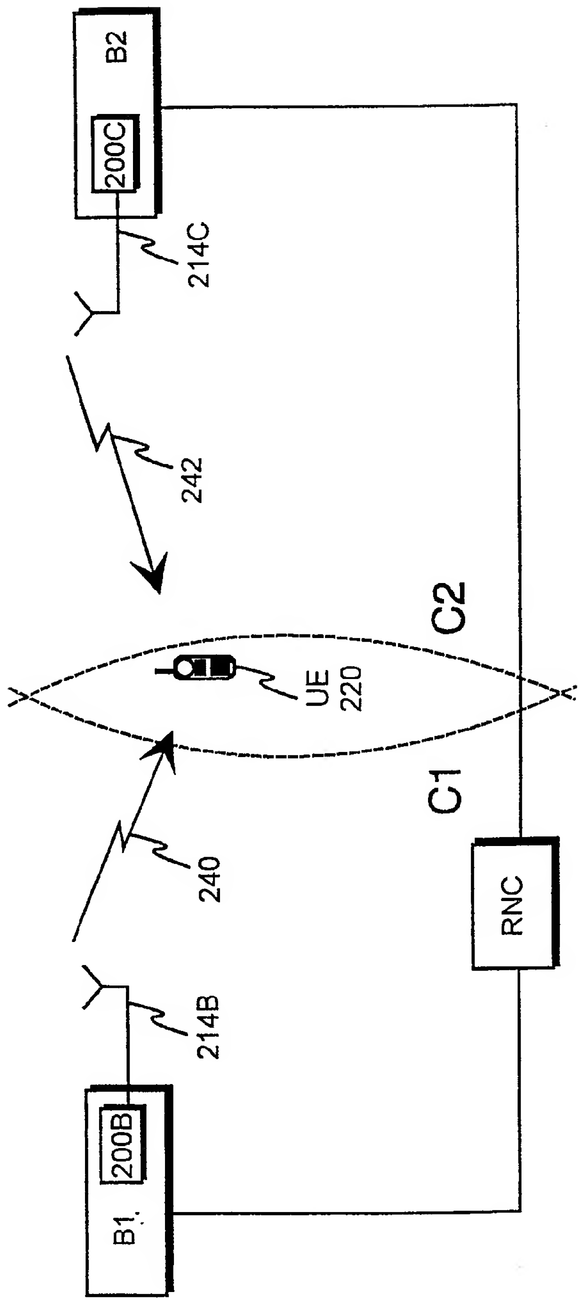
B2
200C
214C
242
C2
UE
220
C1
240
RNC
214B
200B
B1

Fig 5

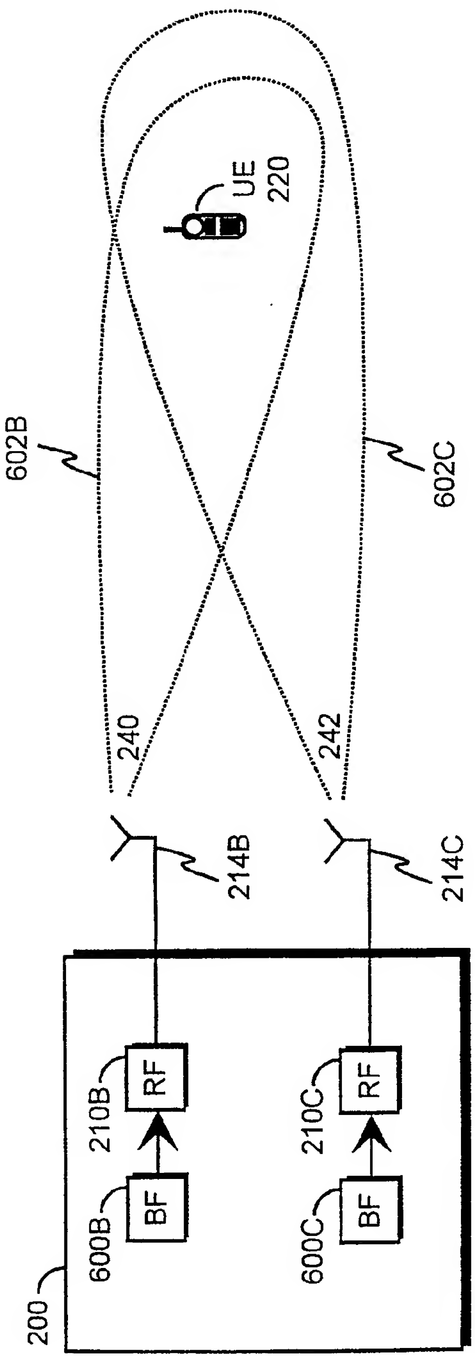
UE
220
602B
602C
240
242
214B
214C
200
600B
BF
210B
RF
600C
BF
210C
RF

Fig 6

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PCT

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2000/28775	23 May 2000 (23.05.2000)	KR

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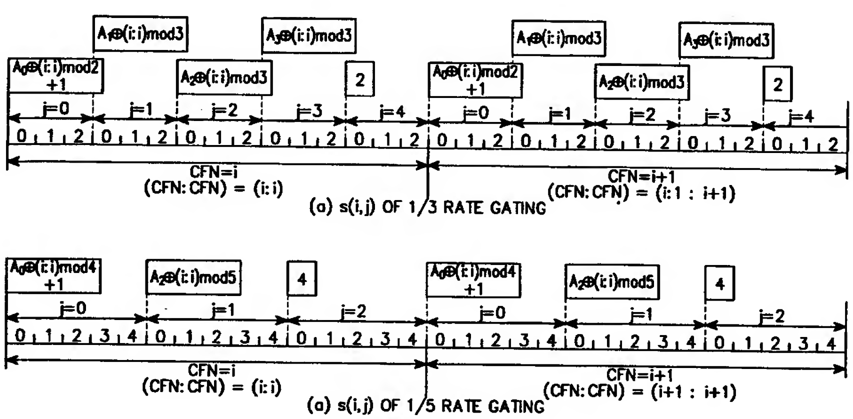
(54) **Title:** APPARATUS AND METHOD FOR GATING DATA ON A CONTROL CHANNEL IN A CDMA COMMUNICATION SYSTEM



(57) **Abstract:** A method for transmitting control data on a downlink and/or uplink channel in a base station and/or mobile station in a mobile communication system. In one embodiment, the base station determines whether there is downlink channel data to transmit to a mobile station. If there is no data to be transmitted over the downlink channel for a predetermined time period, the base station drives a random gating position selector to determine a random gating slot position, gates on the control data at the determined slot position, and gates off the control data at other slot positions. The random position selector determines the gating slot position by calculating a value x by multiplying a system frame number (SFN) of a received signal by a specific integer; selecting n bits starting from a position which is at an x-chip distance from the start point of a scrambling code, which has a period equal to one frame, before a plurality of gating durations used in generating a downlink signal; and determining a gating slot position of a corresponding gating slot group by performing a modulo operation on the selected n bits, where the module operation is by the number of slots in a gating slot group.

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APPARATUS AND METHOD FOR GATING DATA ON A CONTROL CHANNEL IN A CDMA COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a data communication apparatus and method for a CDMA communication system, and in particular, to an apparatus and method for gating data according to whether there is data to transmit.

2. Description of the Related Art

Conventional CDMA (Code Division Multiple Access) mobile communication systems primarily provide voice service. However, future CDMA mobile communication systems will support the IMT-2000 standard, which can provide high-speed data service as well as voice service. More specifically, the IMT-2000 standard can provide high-quality voice service, moving picture service, Internet search service, etc. During data service, IMT-2000 mobile communication systems transmits traffic data over a data channel and transmits control data over a control channel in serial or in parallel with the traffic data. Here, "traffic data" includes voice, picture and packet data, and "control data" includes control and signaling data related to transmission of the traffic data.

In a mobile communication system, data communication is typically characterized by bursts of data transmissions alternating with long periods of non-transmission. The bursts of data are referred to as "packets" or "packages" of data. In the conventional mobile communication system, the base station and the mobile station continuously transmit data on the control channel for a predefined time even when there is no traffic data to transmit. That is, the base station and the mobile station continuously transmit data on the control channel even for the time period where there is no traffic data to transmit, even though this has a deleterious effect on the limited radio resources, base station capacity, power consumption of the mobile station, and interference. This continuous transmission is done in order to minimize the time delay due to sync reacquisition when there is new traffic data to transmit. If there is no data to transmit for a predefined time, the base station and the mobile

station release the data channel and the control channel. In this state, if there is new data to transmit, the base station and the mobile station establish new data channel and control channel.

The IMT-2000 mobile communication system standard defines many states according to channel assignment circumstances and state information existence/nonexistence in order to provide packet data service as well as voice service. For example, a state transition diagram for a cell connected state, a radio bearer activated substate (or RBA mode) and a radio bearer suspended substate (or RBS mode) are well defined in 3GPP RAN TS S2 series S2.03, 99. 04.

FIG. 1A shows state transition in the cell connected state of the conventional mobile communication system. Referring to FIG. 1A, the cell connected state includes a paging channel (PCH) state, a random access channel (RACH)/downlink shared channel (DSCH) state, a RACH/forward link access channel (FACH) state, and a dedicated channel (DCH)/DCH(Dedicated Channel), DCH/DCH+DSCH, DCH/DSCH+DSCH Ctrl (Control Channel) state.

FIG. 1B shows a radio bearer activated substate (i.e., RBA mode) and a radio bearer suspended substate (i.e., RBS mode) within the DCH/DCH, DCH/DCH+DSCH, DCH/DSCH+DSCH Ctrl state.

In many cases, data transmission is performed intermittently, such as for Internet access and file downloading. Therefore, there occurs a non-transmission period between transmissions of packet data. During this period, the conventional data transmission method releases or continuously maintains the data channel. If the dedicated data channel is released, reconnecting the channel requires a long period of time, making it difficult to provide a corresponding service in real time. On the other hand, if the dedicated data channel is maintained, channel resources are wasted.

The downlink (or forward link), which transmits signals from the base station to the mobile station, includes the following physical channels. Physical channels which depart from the scope of the invention will not be described for the sake of simplicity. The downlink physical channels involved in the invention include a dedicated physical control channel (hereinafter, referred to as DPCCH) in which pilot symbols are included for sync acquisition and channel estimation, a dedicated

physical data channel (hereinafter, referred to as DPDCH) for exchanging traffic data with a specific mobile station, and a down link shared channel(DSCH) for transmitting traffic data to multiple mobile stations. The downlink DPDCH includes the traffic data, and the downlink DPCCH includes, at each slot, the control data such as transport format combination indicator (hereinafter, referred to as TFCI), transmit power control (hereinafter, referred to as TPC) information and pilot symbols, which are time multiplexed within one slot. The uplink (or reverse link), which transmits signals from the mobile station to the base station, also has an uplink dedicated control channel and dedicated data channel.

Embodiments of the present invention will be described with reference to the case where the frame length is 10msec and each frame includes 16 slots, i.e., each slot has a length of 0.625msec. Alternatively, embodiments of the present invention will also be described with reference to another case where the frame length is 10msec and each frame includes 15 slots, i.e., each slot has a length of 0.667msec. The slot may have either the same length as a power control group (PCG) or a different length from the power control group. It will be assumed herein that the power control group (0.625msec or 0.667msec) has the same time period as the slot (0.625msec or 0.667msec). The slot includes pilot symbol, traffic data, transport format combination indicator, and power control command bit. The values stated above are given by way of example only.

FIG. 2A shows a slot structure including the downlink DPDCH and DPCCH. In FIG 2A, although the DPDCH is divided into traffic data 1 (Data1) and traffic data 2 (Data2), there is a case where traffic data 1 does not exist and only traffic data 2 exists according to the types of the traffic data. In FIG. 2A, the DPCCH is constructed in the order of TFCI, TPC, and PILOT. Table 1 below shows the symbols constituting the downlink DPDCH/DPCCH fields, wherein the number of TFCI, TPC and pilot bits in each slot can vary according to a data rate and a spreading factor (SF).

Unlike the downlink DPDCH and DPCCH, uplink DPDCH and DPCCH for transmitting signals from the mobile station to the base station are separated by independent channel separation codes.

FIG. 2B shows a slot structure including the uplink DPDCH and DPCCH,

wherein reference numeral 211 indicates a slot structure of the DPDCH and reference numeral 213 indicates a slot structure of the DPCCH. In FIG. 2B, with regard to the DPCCH, the number of TFCI, TPC and pilot bits can vary according to the service option (including the type of the traffic data and the transmit antenna diversity) or a handover circumstance. Tables 2 and 3 below show the symbols constituting the uplink DPDCH and DPCCH fields, respectively.

[Table 1] Downlink DPDCH/DPCCH Fields

Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/Frame			Bits/Slot	DPDCH Bits/Slot		DPCCH Bits/Slot		
			DPDCH	DPCCH	TOT		N_{data1}	N_{data2}	N_{TFCI}	N_{TPC}	N_{pilot}
16	8	512	64	96	160	10	2	2	0	2	4
16	8	512	32	128	160	10	0	2	2	2	4
32	16	256	160	160	320	20	2	8	0	2	8
32	16	256	128	192	320	20	0	8	2	2	8
64	32	128	480	160	640	40	6	24	0	2	8
64	32	128	448	192	640	40	4	24	2	2	8
128	64	64	1120	160	1280	80	14	56	0	2	8
128	64	64	992	288	1280	80	6	56	8	2	8
256	128	32	2400	160	2560	160	30	120	0	2	8
256	128	32	2272	288	2560	160	22	120	8	2	8
512	256	16	4832	288	5120	320	62	240	0	2	16
512	256	16	4704	416	5120	320	54	240	8	2	16
1024	512	8	9952	288	10240	640	126	496	0	2	16
1024	512	8	9824	416	10240	640	118	496	8	2	16
2048	1024	4	20192	288	20480	1280	254	1008	0	2	16
2048	1024	4	20064	416	20480	1280	246	1008	8	2	16

[Table 2] Uplink DPDCH Fields

Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/Frame	Bits/Slot	N_{data}
16	16	256	160	10	10
32	32	128	320	20	20
64	64	64	640	40	40
128	128	32	1280	80	80
256	256	16	2560	160	160
512	512	8	5120	320	320
1024	1024	4	10240	640	640

[Table 3] Uplink DPCCH Fields

Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/Frame	Bits/Slot	N_{pilot}	N_{TPC}	N_{TFCI}	N_{FBI}
16	16	256	160	10	6	2	2	0
16	16	256	160	10	8	2	0	0

16	16	256	160	10	5	2	2	1
16	16	256	160	10	7	2	0	1
16	16	256	160	10	6	2	0	2
16	16	256	160	10	5	1	2	2

Tables 1 to 3 show an example where there exists one DPDCH which is a traffic channel. However, there may exist second, third and fourth DPDCHs according to the service types. Further, the downlink and uplink both may include several DPDCHs. Although the base station transmitter and the mobile station transmitter will be described with reference to the case where there exist three DPDCHs, the number of DPDCHs is not limited.

FIG. 3A shows a structure of the conventional base station transmitter. Referring to FIG. 3A, multipliers 111, 121, 131 and 132 multiply outputs of DPCCH, $DPDCH_1$(or DSCH), $DPDCH_2$ and $DPDCH_3$ data generators 101, 102, 103 and 104, which have undergone channel encoding and interleaving, by their associated gain coefficients G_1, G_2, G_3 and G_4, respectively. The gain coefficients G_1, G_2, G_3 and G_4 may have different values according to circumstances such as the service option and the handover. A multiplexer (MUX) 112 time-multiplexes the DPCCH signal and the $DPDCH_1$ signal into the slot structure of FIG. 2A. A first serial-to-parallel (S/P) converter 113 distributes the output of the multiplexer 112 to an I channel and a Q channel. Second and third S/P converters 133 and 134 S/P-convert the $DPDCH_2$ and $DPDCH_3$ signals and distribute them to the I channel and the Q channel, respectively.

The S/P-converted I and Q channel signals are multiplied by channelization codes C_{ch1}, C_{ch2} and C_{ch3} in multipliers 114, 122, 135, 136, 137 and 138, for spreading and channel separation. Orthogonal codes are used for the channelization codes. The I and Q channel signals multiplied by the channelization codes in the multipliers 114, 122, 135, 136, 137 and 138 are summed by first and second summers 115 and 123, respectively. That is, the I channel signals are summed by the first summer 115, and the Q channel signals are summed by the second summer 123. The output of the second summer 123 is phase shifted by 90° by a phase shifter 124. A summer 116 sums an output of the first summer 115 and an output of the phase shifter 124 to generate a complex signal I+jQ. A multiplier 117 scrambles the complex signal with a PN sequence C_{scramb} which is uniquely assigned to each base station, and a signal separator 118 separates the scrambled signal into a real part and an imaginary part and distributes them to the I channel and the Q channel. The I and Q channel outputs

of the signal separator 118 are filtered by lowpass filters 119 and 125, respectively, to generate bandwidth-limited signals. The output signals of the filters 119 and 125 are multiplied by carriers $\cos\{2\pi f_c t\}$ and $\sin\{2\pi f_c t\}$ in multipliers 120 and 126, respectively, to frequency-up convert the signals to a radio frequency (RF) band. A adder 127 sums the frequency-shifted I and Q channel signals.

FIG. 3B shows a structure of the conventional mobile station transmitter. Referring to FIG. 3B, multipliers 211, 221, 223 and 225 multiply outputs of DPCCH, $DPDCH_1$, $DPDCH_2$ and $DPDCH_3$ data generators 201, 202, 203 and 204, which have undergone channel encoding and interleaving, by their associated channelization codes C_{ch1}, C_{ch2}, C_{ch3} and C_{ch4}, respectively, for spreading and channel separation. Orthogonal codes are used for the channelization codes. The output signals of the multipliers 211, 221, 223 and 225 are multiplied by their associated gain coefficients G_1, G_2, G_3 and G_4 in multipliers 212, 222, 224 and 226, respectively. The gain coefficients G_1, G_2, G_3 and G_4 may have different values.

The outputs of the multipliers 212 and 222 are summed by a first summer 213 and output as an I channel signal, and the outputs of the multipliers 224 and 226 are summed by a second summer 227 and output as a Q channel signal. The Q channel signal output from the second summer 227 is phase shifted by 90° in a phase shifter 228. A summer 214 sums the output of the first summer 213 and the output of the phase shifter 228 to generate a complex signal I+jQ. A multiplier 215 scrambles the complex signal with a PN sequence C_{scramb} which is uniquely assigned to the mobile station, and a signal separator 229 separates the scrambled signal into a real part and an imaginary part and distributes them to the I channel and the Q channel. The I and Q channel outputs of the signal separator 229 are filtered by lowpass filters 216 and 230, respectively, to generate bandwidth-limited signals. The output signals of the filters 216 and 230 are multiplied by carriers $\cos\{2\pi f_c t\}$ and $\sin\{2\pi f_c t\}$ in multipliers 217 and 231, respectively, to frequency-up convert the signals to a radio frequency (RF) band. A adder 218 sums the frequency-up-converted I and Q channel signals.

FIG. 4A shows a conventional method of transmitting the downlink DPCCH and the uplink DPCCH in the RBS mode when transmission of the uplink DPDCH is discontinued. FIG. 4B shows a conventional method of transmitting the downlink

DPCCH and the uplink DPCCH in the RBS mode when transmission of the downlink DPDCH is discontinued.

As illustrated in FIGS. 4A and 4B, the mobile station constantly transmits the uplink DPCCH in the RBS mode in order to avoid a resynchronization acquisition process in the base station. When there is no traffic data to transmit for a long time in the RBS mode, the base station and the mobile station make a transition to an RRC (Radio Resource Control) connection released state. In this state, transmission of the uplink DPDCH is discontinued, but the mobile station transmits pilot symbols and TPC (Transmit Power Control) bits over the DPCCH until the transition is completed, thereby there is an unnecessary interference in the uplink. The interference of the uplink causes a decrease in the capacity of the uplink.

In the conventional method, although continuous transmission of the uplink DPCCH is advantageous in that it is possible to avoid the sync reacquisition process in the base station, it increases interference to the uplink, causing a decrease in the capacity of the uplink. Further, in the downlink, continuous transmission of the uplink transmission power control(TPC) bits causes an interference of the downlink and a decrease in the capacity of the downlink. Therefore, it is necessary to minimize the time required for the sync reacquisition process in the base station, to minimize the interference due to transmission of the uplink DPCCH signal and to minimize the interference due to transmission of the uplink transmission power control(TPC) bits over the downlink.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an apparatus and method for transmitting on and off a DPCCH signal when there is no traffic data(user data or signaling message) to transmit over a data channel for a predefined time in a mobile communication system.

It is another object of the present invention to provide an apparatus and method for gating slot data on the DPCCH in an irregular pattern when there is no traffic data to transmit over the data channel for a predefined time in a mobile communication system.

It is further another object of the present invention to provide an apparatus and method for performing a gated transmission procedure when there is no traffic data to transmit over the data channel for a predefined time, and randomly gating a given slot in a gating slot group unit set during the gated transmission procedure, in a mobile communication system.

It is yet another object of the present invention to provide an apparatus and method in which a base station performs a gated transmission procedure when there is no traffic data to transmit over the data channel for a predefined time, and randomly gates a given slot in a gating slot group unit set during the gated transmission procedure, in a mobile communication system.

It is still another object of the present invention to provide an apparatus and method in which a mobile station performs a gated transmission procedure upon receipt of a message for performing the gated transmission procedure from a base station, and randomly gates a given slot in a gating slot group unit set during the gated transmission procedure, in a mobile communication system.

It is still another object of the present invention to provide an apparatus and method for performing a gated transmission procedure when there is no traffic data to transmit over the data channel for a predefined time, and randomly gating a given slot in a gating slot group unit set as a connected frame number during the gated transmission procedure, in a mobile communication system.

It is still another object of the present invention to provide an apparatus and method for gating slot data on a DPCCH by transmitting a pilot symbol of a slot located before gated on slot and transmitting TFCI and TPC of the gated on slot, in a mobile communication system.

It is still another object of the present invention to provide an apparatus and method for controlling transmission power of control data using power control information while gating data on the DPCCH, in a mobile communication system.

To achieve the above and other objects, there is provided a method for transmitting control data on a downlink channel in a base station for a mobile communication system. The base station determines whether there is downlink data

channel data to transmit to a mobile station. If there is no data to be transmitted over the downlink data channel(DCH or DSCH) for a predetermined time, the base station drives a random position selector to determine a gating slot position, gating on the control data in the determined slot position, and gating off the control data in other positions. All channel data is organized into a stream of frames, each frame includes a plurality of slots, the slots in each frame are divided into a plurality of gating slot groups, and the determined slot position is a randomized slot position in each gating slot group.

Preferably, the random position selector determines the gating slot position by calculating a value x by multiplying a system frame number (SFN) of a received signal by a specific integer; selecting n bits in a position which is at an x-chip distance from a start point of a corresponding Gold code before a plurality of gating durations used in generating a downlink signal; and determining a gating slot position of a corresponding gating slot group by performing a modulo operation by the number of the slots constituting the gating slot group on the selected bits.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1A is a conventional state transition diagram for a packet data service;

FIG. 1B is a conventional state transition diagram between a RBA mode and a RBS mode of the DCH/DCH state;

FIG. 2A is a diagram illustrating a slot structure of downlink DPDCH and DPCCH in a CDMA communication system;

FIG. 2B is a diagram illustrating a slot structure of uplink DPDCH and DPCCH in a CDMA communication system;

FIG. 3A is a diagram illustrating a structure of a conventional base station transmitter in a CDMA communication system;

FIG. 3B is a diagram illustrating a structure of a conventional mobile station transmitter in a CDMA communication system;

FIG. 4A is a diagram illustrating a conventional method of transmitting a downlink DPCCH and an uplink DPCCH when transmission of an uplink DPDCH is discontinued in the RBS mode in a CDMA communication system;

FIG. 4B is a diagram illustrating a conventional method of transmitting the downlink DPCCH and the uplink DPCCH when transmission of a downlink DPDCH is discontinued in the RBS mode in a CDMA communication system;

FIG. 5A is a diagram illustrating a structure of a base station transmitter for gating data on the DPCCH according to an embodiment of the present invention;

FIG. 5B is a diagram illustrating a structure of a mobile station transmitter for gating data on the DPDCH according to an embodiment of the present invention;

FIG. 5C is a diagram illustrating a structure of a base station transmitter with a gating position selector, for gating data on the DPDCH according to an embodiment of the present invention;

FIG. 5D is a diagram illustrating a structure of a mobile station transmitter with a gating position selector, for gating data on the DPDCH according to an embodiment of the present invention;

FIG. 6A is a diagram illustrating a method for transmitting a signal according to a regular or gated transmission pattern for an uplink DPCCH in the RBS mode according to an embodiment of the present invention;

FIG. 6B is a diagram illustrating another method for transmitting a signal according to a regular or gated transmission pattern for an uplink DPCCH in the RBS mode according to an embodiment of the present invention;

FIG. 7A is a diagram illustrating a method for transmitting a signal when an uplink DPDCH message is generated while gating an uplink DPCCH in the RBS mode according to an embodiment of the present invention;

FIG. 7B is a diagram illustrating another method for transmitting a signal when an uplink DPDCH message is generated while gating an uplink DPCCH in the RBS mode according to an embodiment of the present invention;

FIG. 8A is a diagram illustrating a method for transmitting downlink and uplink signals when transmission of a downlink DPDCH is discontinued according to an embodiment of the present invention;

FIG. 8B is a diagram illustrating a method for transmitting downlink and uplink signals when transmission of an uplink DPDCH is discontinued according to an embodiment of the present invention;

FIG. 8C is a diagram illustrating another method for transmitting downlink and uplink signals when transmission of the downlink DPDCH is discontinued according to an embodiment of the present invention;

FIG. 8D is a diagram illustrating another method for transmitting downlink and uplink signals when transmission of the uplink DPDCH is discontinued

according to an embodiment of the present invention;

FIG. 9A is a diagram illustrating a method for transmitting downlink and uplink signals when transmission of a downlink DPDCH is discontinued (gated transmission for the downlink DPCCH) according to an embodiment of the present invention;

FIG. 9B is a diagram illustrating a method for transmitting downlink and uplink signals when transmission of an uplink DPDCH is discontinued (gated transmission for downlink DPCCH) according to an embodiment of the present invention;

FIG. 10A is a diagram illustrating a structure of a base station transmitter according to another embodiment of the present invention;

FIG. 10B is a diagram illustrating a structure of a mobile station transmitter according to another embodiment of the present invention;

FIG. 11A is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a first embodiment of the present invention;

FIG. 11B is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a second embodiment of the present invention;

FIG. 11C is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a third embodiment of the present invention;

FIG. 11D is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a fourth embodiment of the present invention;

FIGS. 12A and 12B are diagrams illustrating gated transmission for downlink and uplink DPCCHs according to a fifth embodiment of the present invention;

FIG. 12C is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a sixth embodiment of the present invention;

FIG. 12D is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a seventh embodiment of the present invention;

FIG. 12E is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to an eighth embodiment of the present invention;

FIG. 13A is a diagram illustrating a method for determining a position selection bit during gated transmission of the downlink and uplink DPCCHs according to the first embodiment of the present invention;

FIG. 13B is a diagram illustrating a method for determining a position selection bit during gated transmission of the downlink and uplink DPCCHs according to the second embodiment of the present invention;

FIG. 13C is a diagram illustrating a method for determining a position selection bit during gated transmission of the downlink and uplink DPCCHs according to the third embodiment of the present invention;

FIG. 13D is a diagram illustrating a method for determining a position selection bit during gated transmission of the downlink and uplink DPCCHs according to the fourth embodiment of the present invention;

FIG. 14A is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a ninth embodiment of the present invention;

FIG. 14B is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a tenth embodiment of the present invention;

FIG. 14C is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to an eleventh embodiment of the present invention;

FIG. 14D is a diagram illustrating gated transmission for downlink and uplink DPCCHs according to a twelfth embodiment of the present invention;

FIG. 15A is a diagram illustrating a method for extracting a partial sequence required to generate a gated transmission pattern from an uplink scrambling code according to an embodiment of the present invention;

FIG. 15B is a diagram illustrating a method for extracting an n-bit sequence required to generate a gated transmission pattern from a fixed sequence according to an embodiment of the present invention;

FIG. 16 is a diagram illustrating a structure of a gating position selector for selecting a gating position by using the uplink scrambling code of FIG. 15A and the fixed sequence of FIG. 15B together with CFN according to an embodiment of the present invention;

FIG. 17A is a diagram illustrating a power control time relationship when 1/3 rate gating is applied to both the downlink and the uplink according to an embodiment of the present invention;

FIG. 17B is a diagram illustrating a power control time relationship when 1/5 rate gating is applied to both the downlink and the uplink according to an embodiment of the present invention;

FIG. 18A is a diagram illustrating a power control time relationship when 1/3 rate gating is applied to only the downlink according to an embodiment of the present invention; and

FIG. 18B is a diagram illustrating a power control time relationship when 1/5 rate gating is applied to only the downlink according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the present invention will be described herein below with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary detail.

The term "normal transmission" as used herein refers to continuously transmitting TFCI, TPC and pilot symbol included in the downlink or uplink DPCCH. Further, the term "gated transmission" refers to transmitting TFCI, TPC and pilot symbol included in the downlink or uplink DPCCH, only at a specific power control group (or slot) according to a predetermined pattern, or refer to gated on transmission of a DPCCH signal only at a pilot symbol of a slot located before gated on slot and TFCI and TPC of the gated on slot according to a predetermined gated on pattern. The information, transmission of which is discontinued in the downlink DPCCH during gated transmission, may include either all or some of the TFCI, TPC and pilot symbol in one power control group (or slot). In addition, the term "gating position selection" as used herein refers to selecting a position of a slot for transmitting data on the DPCCH during gated transmission, and "gating position" refers to the slot selected for transmitting the control data. Further, the term "control data" as used herein refers to a DPCCH signal, and the term "traffic data" refers to signaling data and/or user data which is transmitted in bursts between the base station and the mobile station. TFCI, TPC, FBI(Feedback Indicator) and pilot symbol are included in the "control data". Although the invention will be described with reference to an example of gating data on the DPCCH, the gated transmission method according to the present invention can also be applied to the case of gating control data on any other channel which periodically transmits control data.

The gated transmission operation, which will be described later, can be applied to either the case when the gated transmission unit is equal to the slot unit, or the case when the gated transmission unit is not equal to the slot unit. When the gated transmission unit is not equal to the slot unit, it is preferable to gate TPC, TFCI and pilot symbol differently. That is, an nth pilot symbol and (n+1)th TFCI and TPC are set as a gated transmission unit.

In addition, since performance at the beginning of a frame is very important, the preferred embodiments of the present invention locate the TPC, which is for controlling the power of the first slot of the next frame, at the last slot of one frame. That is, TPC bits for the downlink DPCCH and the uplink DPCCH are located at the last slot of the nth frame, and power of the first slot of the (n+1)th frame is controlled using the TPC bits existing at the last slot of the nth frame.

In an exemplary embodiment of the present invention, when the mobile communication system performs gated transmission, the base station and the mobile station determine positions of the gating slots according to either a predetermined regular pattern, or an irregular pattern determined by setting given slots in a gating slot group as gating positions using the System Frame Number (SFN) and the Connection Frame Number (CFN). Further, in the mobile communication system, a DPDCH and one frame of the DPDCH can be comprised of a plurality of slots. In the various embodiments of the present invention, one frame can be comprised of 15 or 16 slots, and the invention will be described here for both cases. Below, the gated transmission operation performed in the regular pattern will be described with reference to the case where one frame is comprised of 16 slots, and the gated transmission performed in the irregular pattern will be described with reference to the case where one frame is comprised of 15 slots.

The invention will be described focusing on the process of performing 1/3 and 1/5 rate gated transmission on the downlink and uplink DPCCHs of FIGS. 2A and 2B. It is also possible to determine gating positions according to random patterns as shown in FIGS. 15A, 15B and 16.

A hardware structure according to an embodiment of the invention will be described below.

FIG. 5A shows a structure of a base station transmitter according to an embodiment of the present invention. The base station transmitter is different from the conventional one of FIG. 3A in that with regard to the downlink DPCCH, the output of the multiplier 111 is gated by a gated transmission controller 141. That is, the gated transmission controller 141 performs gated transmission on a pilot symbol of one slot of the downlink DPCCH and TFCI and TPC bits of the next slot in a

pattern scheduled with the mobile station, when the traffic data to be transmitted over the downlink DPDCH is not generated for a predetermined time or when traffic data is not received over the uplink DPDCH for a predetermined time. In addition, the gated transmission controller 141 performs gated transmission on one power control group (or one entire slot) including the pilot symbols, TFCI and TPC bits for the downlink DPCCH at a power control group (or time slot) scheduled with the mobile station in the RBS mode where the traffic data is not transmitted over the downlink and uplink DPDCHs.

When the downlink and uplink DPCCH signals are simultaneously gated, the downlink gating pattern is equal to the uplink gating pattern, but an offset may exist between them for efficient power control. The offset can be given as a system parameter or can be known by a message indicating the start of gated transmission. The gating start indication message is transmitted from the base station to the mobile station to indicate a start point of gated transmission and a gating rate, after traffic data to be transmitted over the DPDCH is not generated for a predetermined time. This message can also be transmitted from the mobile station to the base station. In addition, the base station can determine a gating start indication message in response to a gating request of the mobile station, and transmit the determined message to the mobile station.

The gated transmission controller 141 can gate either the slot data on the DPCCH or the control data of multiple slots. One slot of the DPCCH is comprised of the control data such as pilot symbol, TFCI and TPC (in the mobile station, FBI is further included). During gated transmission, the gated transmission controller 141 can gate the entire control data included in the slot of the gating position. As an alternative method, the gated transmission controller 141 can gate a pilot symbol of an nth slot duration located before an (n+1)th slot of the gating position, and TPC and TFCI bits of the (n+1)th slot. This embodiment of the present invention will be described with reference to the latter method.

In addition, the gated transmission controller 141 locates the TPC bits at the last slot of one frame, where the TPC bits are for power controlling the first slot of the next frame in order to guarantee performance of the beginning part of the next frame. That is, the TPC bits for the downlink DPCCH and the uplink DPCCH are located at the last slot of the nth frame, and power of the first slot of the (n+1)th

frame is controlled using the TPC bits existing at the last slot of the nth frame.

When the mobile station performs gated transmission and the base station does not perform gated transmission, the base station transmitter determines a TPC (Transmit Power Control) bit by measuring the one DPCCH slot signal discontinuously transmitted from the mobile station and then transmits the determined TPC bit at every slot until the base station determines new TPC bit by measuring another up link DPCCH slot signal.

FIG. 5B shows a structure of a mobile station transmitter according to an embodiment of the present invention. The mobile station transmitter is different from the conventional one of FIG. 3B in that a gated transmission controller 241 is provided to gate transmission of the uplink DPCCH. That is, the gated transmission controller 241 performs gated transmission on one power control group (or one entire slot) including the pilot symbols, TFCI, FBI and TPC bits for the uplink DPCCH at a power control group (or time slot) scheduled with the base station, when traffic data to be transmitted over the downlink and uplink data channels(DPDCH or DSCH) is not generated for a predetermined time or when traffic data to be transmitted over the uplink DPDCH is not generated for a predetermined time.

Now, a description will be made of a transmission signal structure of the base station and the mobile station according to an embodiment of the present invention.

FIG. 6A shows a method for transmitting an uplink DPCCH signal according to a regular or gated transmission pattern when there is no data to be transmitted over the DPDCH for a predetermined period of time according to an embodiment of the present invention. In FIG. 6A, reference numerals 301, 302, 303 and 304 show different gating rates according to duty cycles (hereinafter, referred to as DC). Herein, the "duty cycle" (or "DC") and the "gating rate" are used to refer to the same thing. Reference numeral 301 shows a conventional method for transmitting the uplink DPCCH without gating (DC=1), and reference numeral 302 shows a method for regularly transmitting every other power control group (or time slot), when DC=1/2 (only 1/2 of all the slots in one frame are transmitted). Reference numeral 303 shows a method for regularly transmitting every fourth

slot(3rd, 7th, 11th and 15th slots), when DC=1/4 (only 1/4 of all the slots in one frame are transmitted). Reference numeral 304 shows a method for regularly transmitting every eighth slots (7th and 15th slots), when DC=1/8 (only 1/8 of all the slots in one frame are transmitted).

In the embodiment of FIG. 6A, when DC=1/2 and 1/4, although the gated transmission controller 241 of the mobile station regularly gates the slots of the uplink DPCCH, it is also possible to gate arbitrary slots according to the corresponding DC. That is, when DC=1/2, it is also possible to continuously gate adjacent arbitrary slots according to an irregular pattern, rather than regularly transmitting every other slot. Further, when DC=1/2, it is also possible to continuously transmit half of all the slots at the second half (8th to 15th slots) of the frame. When DC=1/4, it is also possible to continuously transmit 1/4 of all the slots beginning at a 3/4 point of the frame (i.e., 12th to 15th slots). When DC=1/8, it is also possible to continuously transmit 1/8 of all the slots beginning at a 7/8 point of the frame (i.e., 14th to 15th slots).

The gating rate can be varied during gated transmission. For this, the mobile station and the base station should know when and which gating rate they will use, so that it is necessary to transmit a message for this. The gating rate is determined at the start of gated transmission and preferably, not changed during the gated transmission.

FIG. 6B shows a method for transmitting a signal according to a regular or gated transmission pattern for the uplink DPCCH according to another embodiment of the present invention. In FIG. 6B, reference numerals 305, 306 and 307 show different gating rates according to a ratio of a duty cycle DC. Reference numeral 305 shows a method for transmitting two consecutive slots at regular locations (2^{nd}-3^{rd}, 6^{th}-7^{th}, 10^{th}-11^{th} and 14^{th}-15^{th} slots), when DC=1/2 (only 1/2 of all the slots in one frame are transmitted). Reference numeral 306 shows a method for transmitting two consecutive slots at regular locations (6^{th}-7^{th} and 14^{th}-15^{th} slots), when DC=1/4 (only 1/4 of all the slots in one frame are transmitted). Reference numeral 307 shows a method for transmitting two consecutive slots at regular locations (14^{th}-15^{th} slots), when DC=1/8 (only 1/8 of all the slots in one frame are transmitted).

In the embodiment of FIG. 6B, when DC=1/2 and 1/4, although the gated

transmission controller 241 of the mobile station regularly gates the slots of the uplink DPCCH, it is also possible to gate arbitrary slots out of all the slots according to the corresponding DC. That is, when DC=1/2, it is also possible to continuously gate 4 consecutive slots (e.g., 2^{nd}-5^{th} slots) according to an irregular pattern, rather than regularly transmitting every other 2 consecutive slots.

Next, a description will be made of signal transmission diagrams of the base station and the mobile station according to another embodiment, in which the slot gating positions are selected such that a signal should be transmitted at one of consecutive three or five consecutive slots. The embodiment will be described for the gating rate of 1/3 or 1/5, in the case where one frame includes 15 slots (i.e. power control groups).

FIG. 5C shows a structure of a base station transmitter with a gating position selector according to an embodiment of the present invention. The base station transmitter is different from that of FIG. 5A in that the positions of the transmission slots for the downlink DPCCH are selected by a gating position selector 142.

FIG. 5D shows a structure of a mobile station transmitter with a gating position selector according to an embodiment of the present invention. The base station transmitter is different from that of FIG. 5B in that the positions of the transmission slots for the uplink DPCCH are selected by a gating position selector 242.

Arranging the gating positions of the slots irregularly is to prevent electromagnetic wave-related bad effects due to the power of the regularly transmitted signals. In this embodiment, a scrambling code is used to irregularly gating the transmission signals.

One method for selecting the gating positions of the gating slot is to use the system frame number (SFN) of a downlink signal immediately before transmission of an uplink signal, and a scrambling code generated to descramble a received downlink signal in the mobile station. The mobile station reads a code bits in a specific position of the scrambling code using the SFN of the downlink signal, and determines the gating slots using the read value. Since the SFN value of 0 to 71 is continuously transmitted over a broadcasting channel from the base station, the

mobile station can read the SFN by receiving data on the broadcasting channel. For the scrambling code, a secondary scrambling code or a primary scrambling code can be used. If the base station knows the gating position of the mobile station, it can exactly receive the data gated-on by the mobile station. Therefore, it is preferable that the gating position should be agreed between the transmission side and the receiving side. For this agreement, this embodiment uses a scrambling code with a random property, which is equally used by the base station and the mobile station, and the SFN for reducing the periodicity, thereby to determine a position of a slot to be gated.

The gating position controller 242(FIG. 5D) of the mobile station determines a position of the slot to be gated on by using a Gold code, which is a real part of a scrambling code generated internally to descramble a received signal, and the SFN of the received signal. When DC=1/3, the gating position controller 242 selects one slot in an arbitrary position out of 3 slots (gating slot group), and when DC=1/5, the gating position controller 242 selects one slot in an arbitrary position out of 5 slots (gating slot group). Herein, the 3-slot duration for DC=1/3 and the 5-slot duration for DC=1/5 will be referred to as "gating duration" or "gating slot group".

A first method for randomly determining the slot to be gated on in a gating slot group unit according to an embodiment of the present invention is determined in the following order. FIGs 13A, 13B, 14A, and 14B are related to this method

1. A system frame number (SFN) 0 to 71 of a signal received immediately before transmission is multiplied by an integer between 1 and 35. Let the calculation result be 'x' ($0 \leq x \leq 2485$).

2a. For DC=1/3, one bit of real part of scrambling code is selected in the position which is at an x-chip apart from the boundary of gating group , as shown in FIG. 13A.. The selected one bit can be used for determining the position of gating slot in the following gating slot group. That is, the position of gating slot in current gating slot group can be determined based on the one bit selected in the previous gating slot group

2b. For DC=1/5, two bits of real part of scrambling code are selected in the position which is at an x-chip apart from the boundary of gating group, as shown in FIG. 13B.

3a. For DC=1/3, the position of a gating slot to be transmitted is determined using the selected one bit. Since only one bit is used, the position is randomly selected between two slots determined by the agreement, out of three transmittable slot positions.

3b. For DC=1/5, the position of a slot to be transmitted is determined using the selected two bits. Since the two bit are used, the positions are randomly selected among four slot positions determined by the agreement, out of five transmittable slot positions.

4. When the SFN is changed, the above procedure is performed again from step 1 with a new value. In this case, the integer value used in step 1 (ranges from 1 to 35) is maintained.

For the positions of the transmission gating slots of the downlink , the downlink gating pattern (or downlink gated transmission pattern) is equal to that of uplink. For efficient power control, however, a specific offset may exist between uplink and downlink gating-on slot. This offset is given as a system parameter. In addition, the downlink gating pattern can be determined using preset positions, regardless of the uplink gating pattern.

FIG. 14A shows a method for selecting gating positions of the gating slot groups for DC=1/3. The gating position controller 242 of the mobile station receives a scrambling code and SFN of the downlink signal, and selects one bit in the real part of the scrambling code. The selected one bit is utilized for determining the gating-on slot of the next gating slot group. In other words, the position of gating-on slot in current gating slot group is determined based on the one bit selected in the previous gating slot group. In general, the time difference in unit of slot between current gating slot group and the gating slot group from which the one bit is selected can be larger than one. Here, the base station transmits the downlink gating slot in the position which is a predetermined number of slots off from the position of the

gating slot received in the uplink.

FIG. 14B shows a method for selecting gating positions of the gating slot groups for DC=1/5. The gating position controller 242 of the mobile station receives a scrambling code and SFN of the downlink signal, and selects two bits in the real part of the scrambling code. The selected two bits are utilized for determining the gating-on slot of the next gating slot group. In other words, the position of gating-on slot in current gating slot group is determined based on the two bits selected in the previous gating slot group. In general, the time difference in unit of slot between current gating slot group and the gating slot group from which the two bits are selected can be larger than one. Here, the base station transmits the downlink gating-on slot in the position which is a predetermined number of slots off from the position of the gating-on slot received in the uplink.

When determining a location of real part of scrambling code, it is also possible to use the channelization code number for the downlink signal, which is uniquely applied to each mobile station, in addition to the SFN. Using the channelization code for the downlink signal is to prevent the downlink signals for the different mobile stations from transmitting the gating slots in the same time position.

Another method for selecting the gating slot in a gating slot group is shown in FIGs 13C, 13D, 14C, and 14D. In this method, the gating positions are determined by performing modulo-3 or modulo-5 operation on the decimal value of N bits from specific portion of real part of scrambling code.

A second method for randomly selecting an arbitrary slot in a gating slot group unit according to this embodiment of the present invention is determined in the following order.

1. A system frame number (SFN) 0 to 71 of a signal received immediately before transmission is multiplied by an integer between 1 and 35. Let the calculation result be 'x'($0 \le x \le 2485$).

2a. For DC=1/3, N bits of the real part of scrambling code are selected in the

position which is at an x-chip apart from the boundary of gating slot group, as shown in FIG 13C. The selected N bits can be used for determining the position of gating slot in the following gating slot group. That is, the position of gating slot in current gating slot group can be determined based on the N bits selected in the previous gating slot group.

2b. For DC=1/5, N bits of the real part of scrambling code are selected in the position which is at an x-chip apart from the boundary of gating slot group, as shown in FIG 13D. The selected N bits can be used for determining the position of gating slot in the following gating slot group. That is, the position of gating slot in current gating slot group can be determined based on the N bits selected in the previous gating slot group.

3a. For DC=1/3, the position of a gating slot to be transmitted is determined using a value obtained by performing a modulo-3 operation on a decimal value corresponding to the selected N bits. Since the resulting value of the modulo-3 operation is one of 0, 1 and 2, each value designates the position of an arbitrary slot in the gating duration (or gating slot group).

3b. For DC=1/5, the position of a slot to be transmitted is determined using a value obtained by performing a modulo-5 operation on a decimal value corresponding to the selected N bits. Since the resulting value of the modulo-5 operation is one of 0, 1, 2, 3 and 4, each value designates the position of an arbitrary slot in the gating gating slot group.

4. When the SFN is changed, the above procedure is performed again from step 1 with a new value of offset x. In this case, the integer value used in step 1 (ranges from 1 to 35) is maintained.

The gating slot position selecting method selects the gating position of the gating slot group using the real part of scrambling code and SFN which ranges from 0 to 71. Therefore, the gating-on slot pattern has a period of 720msec. In order to make the period of gating-on pattern greater than 720msec, the x value can be changed whenever the SFN becomes a specific value.

FIG. 14C shows a method for selecting gating positions of the gating slot

groups for DC=1/3. The gating position controller 242 of the mobile station receives a scrambling code and SFN of the downlink signal, selects N bits in the real part of the scrambling code. The selected one bit is utilized for determining the gating slot of the next gating slot group. In other words, the position of gating slot in current gating slot group is determined based on the modulo-3 operation of N bits selected in the previous gating slot group. In general, the time difference in unit of slot between current gating slot group and the gating slot group from which N bits are selected can be larger than one. Here, the base station transmits the downlink gating slot in the position that is a predetermined number of slots off from the position of the gating slot received in the uplink..

FIG. 14D shows a method for selecting gating positions of the gating slot group for DC=1/5. The gating position controller 242 of the mobile station receives a scrambling code and SFN of the downlink signal, and selects N bits in the real part of the scrambling code. The selected N bits are utilized for determining the gating slot of the next gating slot group. In other words, the position of gating slot in current gating slot group is determined based on the modulo-5 operation of N bits selected in the previous gating slot group. In general, the time difference in unit of slot between current gating slot group and the gating slot group from which N bits are selected can be larger than one. Here, the base station transmits the downlink gating slot in the position that is a predetermined number of slots off from the position of the gating slot received in the uplink.

Arranging the gating positions of the slots irregularly is to prevent electromagnetic wave-related bad effects due to the power of the regularly transmitted signals. In order to randomly gate the transmission signals, this embodiment gives an example of using an arbitrary number for distinguishing the uplink/downlink frame together with an uplink scrambling code or a fixed sequence. The arbitrary number for distinguishing the uplink/downlink frame can become SFN or CFN (Connection Frame Number), and can also become an arbitrary system parameter for determining the uplink/downlink frame. The second method for gating a randomized slot in a gating slot group according to this embodiment of the present invention randomly gates a randomized slot in the using the CFN. That is, the second random gating method according to this embodiment of the present invention uses the CFN as an arbitrary number for distinguishing the uplink/downlink frame, and the CFN is a value which is equally used by every base station in

communication with a specific mobile station (or user equipment). Further, the CFN is indicated by 8 bits and is a frame number having a repetition period of 256(0 to 255).

FIG. 15A shows a method for extracting a partial sequence required in generating a gating pattern from an uplink scrambling code. The scrambling code for the uplink signal is used for distinguishing the user equipment (UE) in the mobile communication system, and is classified into a long scrambling code and a short scrambling code. The long scrambling code has a length of 33,554,432 bits, and is applied to a one-frame signal transmitted from the user equipment using only a 38400-bit length code consisting of the 0^{th} to 38399^{th} bits of the full length, to distinguish the user equipment. The short scrambling code has a length of 256 bits and is repeated 150 times within one frame transmitted from the user equipment. The short scrambling code is a user identification scrambling code used for the case where the base station includes a separate device such as an interference remover.

Referring to FIG. 15A, a slot 1511 is a first slot of a frame 1501 and has a slot number 0. For a scrambling code applied to the slot 1511, the long scrambling code uses 0^{th} to 2559^{th} bits, and the short scrambling code repeats a scrambling code of 0^{th} to 255^{th} bits 10 times. In the following description, the long scrambling code and the short scrambling code will be both called a scrambling code. The long scrambling code and short scrambling code can be used in this invention. In FIG. 15A, reference numeral 1512 indicates a 0^{th} bit of the scrambling code of the first slot 1511, reference numeral 1513 indicates a 1^{st} bit of the scrambling code, and reference numeral 1514 indicates 2559^{th} bit of the scrambling code.

In FIG. 15A, reference numeral 1501 indicates 1-frame duration The frame 1501 is comprised of 15 slots from the 0^{th} slot 1511 to the 14^{th} slot 1519. A description of a method for selecting the gating slot position of the gating slot group in frame 1501 will be made below.

The frame 1501 is divided into gating slot groups each including 3 or 5 slots according to the DC. That is, for DC=1/3, the frame 1501 is divided into 5 gating slot groups each including 5 slots (i.e., gating slot group #0 includes 0^{th} to 2^{nd} slots, gating slot group #1 includes 3^{rd} to 5^{th} slots, gating slot group #2 includes 6^{th} to 8^{th} slots, gating slot group #3 includes 9^{th} to 11^{th}, and gating slot group #4 includes 12^{th}

to 14th slots). For DC=1/5, the frame 1501 is divided into 3 gating slot groups each including 5 slots (i.e., gating slot group #0 includes 0th to 4th slots, gating slot group #1 includes 5rd to 9th slots, gating slot group #2 includes 10th to 14th slots).

In FIG. 15A, the frame 1501 is divided into 3 or 5 gating slot groups according to the DC, and each gating slot group has an offset value that is equal to the gating slot group numbers for the respective gating slot groups. For DC=1/3, the offset values of gating slot group#0 is 0, the offset value of gating slot group#1 is 1, the offset value of gating slot group#2 is 2, the offset value of gating slot group#3 is 3, and the offset value of gating slot group#4 is 4. For DC=1/5, the offset value of gating slot group#0 is 0, the offset value of gating slot group#1 is 1, and the offset value of gating slot group#2 is 2. Application of the offset values will be described below.

1551st to 1554th bits of FIG. 15A indicate the n extracted bits. Therefore, the n bits of 1551st to 1554th bits are selected from the 0th bit 1512 to the 2559th bit 1514 of the scrambling code used for the slot 1511 according to the prescribed agreement between a base station and a mobile station. Here, 'n' is a multiple of 8, and is a positive number which can be arbitrarily set. A method for selecting the n bits from bit 1551 to bit 1554 in the scrambling code applied to the slot 1511 is as follows. In order to decide the gating slot in current gating slot group, n bits from the scrambling code used in the previous gating slot group with an offset is utilized, where the offset is applied to the first bit of the scrambling code of the previous gating slot group.

(1) For DC=1/3, the frame is divided into 5 gating slot groups #0 to #4. For the n bits used for selecting the gating position of the gating slot group #0, n bits starting from the 30724th bit of the scrambling code of the preceding frame are used.. Here, the 30724th bit is the bit to which offset of 4 is applied from the boundary of the gating slot group#4 of the previous frame. That is, it is the 30720th bit, which is the start bit of the scrambling code applied to the gating slot group #4 of the previous frame. And the start bit of the n bits(which will be used for the gating slot group #0 in current frame) is 30724th bit which is determined by applying an offset value of gating slot group #4(=4) of the previous frame of the gating slot group #0. Accordingly, the start bit for selecting a scrambling code used in selecting the gating position to be applied to the gating slot group #0 becomes the 30724th bit.

Similarly, for the n bits used for selecting the gating position in the gating slot group #1, n bits are sequentially extracted starting from the 0^{th} bit of the scrambling code of the gating slot group #0 because the offset value for the gating slot group#0 is 0. For the n bits used for selecting the gating position in the gating slot group #2, n bits are sequentially extracted starting from the 7681^{st} bit of the scrambling code by applying an offset value (i.e., offset value=1) of the gating slot group #1. For the n bits used for selecting the gating position in the gating slot group #3, n bits are sequentially extracted starting from the 15362^{nd} bit of the scrambling code by applying an offset value (i.e., offset value=2) of the gating slot group #2. For the n bits used for selecting the gating position in the gating slot group #4, n bits are sequentially extracted starting from the 23043^{rd} bit of the scrambling code by applying an offset value (i.e., offset value=3) of the gating slot group #3. As described previously, for the n bits used for selecting the gating position in the gating slot group #0, n bits are sequentially extracted starting from the 30724^{th} bit of the scrambling code by applying an offset value (i.e., offset value=4) of the gating slot group #4 of the previous frame. In other words, the n bits used to determine the gating slot position within gating slot group #(p+1) are selected starting from bit number y, where y= {1^{st} bit of gating slot group #(p)} + {the offset of gating slot group #(p)} except for determining the gating slot position within gating slot group#0. In case of the gating slot position within gating slot group#0, n bits used to determine the gating slot position within gating slot group#0 are selected starting from bit number y, where y={1^{st} bit of gating slot group#4 of the previous frame} + {the offset of gating slot group#4}.

In other words, the n bits used to determine the gating slot position within gating slot group #(p+1) are selected starting from bit number y, where y= {1^{st} bit of gating slot group #(p)} + {the offset of gating slot group #(p)} except for determining the gating slot position within gating slot group#0. In case of the gating slot position within gating slot group#0, n bits used to determine the gating slot position within gating slot group#0 are selected starting from bit number y, where y={1^{st} bit of gating slot group#4 of the previous frame} + {the offset of gating slot group#4}.

(2) For DC=1/5, the frame is divided into 3 gating slot groups of the gating slot groups #0 to #2. For the n bits used for selecting the gating position of within the gating slot group #0, n bits are sequentially extracted starting from the 25602^{nd}

bit of the scrambling code of the previous frame. For the n bits used for selecting the gating position of the gating slot group #1, n bits are sequentially extracted starting from the 0^{th} bit of the scrambling code. For the n bits used for selecting the gating position of the gating slot group #2, n bits are sequentially extracted starting from the 12801^{st} bit of the scrambling code.

FIG. 15B is a diagram for explaining a third method for performing random gating according to an embodiment of the present invention. This method is implemented using CFN. FIG. 15B shows a method for extracting an n-bit sequence required in generating a gating pattern from a fixed sequence A.

Referring to FIG. 15B, the n-bit(16 bit) sequences are used in determining the irregular transmission pattern in each gating slot group. The n-bit(16 bit) sequences are obtained by applying offset j(0, 1, 2, 3) shift selection from the fixed sequence (ie, A=a0, a1, a2 ... a18=1011010011011101001). For DC 1/5, A_0 and A_1 can be used. The A_0 have 16 bits(a0 to a15) and A_1 have 16 bits(a1 to a16). For DC 1/3, A_0, A_1, A_2 and A_3 can be used. At that case, the A_0 is a0 to a15 extracted from the fixed sequence A with offset 0, the A_1 is a1 to a16 extracted from the fixed sequence A with offset 1, the A_2 is a2 to a17 extracted from the fixed sequence A with offset 2, and the A_3 is a3 to a18 extracted from the fixed sequence A with offset 3. The A_0 will be used for calculating the gating slot of the 0'th gating slot group and the A_1 will be used for calculating the gating slot of the 1'th gating slot group. The A_2 and A_3 will be used for calculating the gating slot of the 2'th and 3'th gating slot group when the DC is 1/3. Therefore, the A_0 and A_1 or A_0 to A_3 is periodically used in each frame. In FIG. 15B, the n-bit sequence is shown which is obtained by applying the offset to the fixed sequence A where the value of offset is equal to the current gating slot group number. Since the sequence to be used in each gating slot group is selected by applying an offset to the fixed sequence A, the following sequences cannot be used A.

1. The case where the sequences selected after applying the offset become equal.

Ex) A=10101010101010101010

Offset 0 : A_0=10101010101010101010

Offset 1 : A_1=01010101010101010101

Offset 2 : A_2=10101010101010101010

2. Sequence of all 1's or all 0's
Ex) A=0000000000000000000000
Ex) A=1111111111111111111111

An exemplary hardware structure for selecting the gating position using the n bits used in selecting the gating slot position of FIGS. 15A and 15B is shown in FIG. 16. FIG. 16 shows an apparatus to perform a method for selecting the gating slot position by using the uplink scrambling code shown in FIG. 15A together with CFN, or the fixed sequence A shown in FIG. 15B together with the CFN.

Referring to FIG. 16, a memory 1601 stores the n bits of the scrambling code selected in the manner described with reference to FIG. 15A or stores the n bits(ie, 16bit) from the fixed sequence Aaccording to the selecting manner described with reference to FIG. 15B.

A memory 1603 stores the repeated CFN, by the n-bit(16 bits) length, which is equally used in the user equipment and a base station in communication with the user equipment. The CFN is repeatly increased 0 to 255 which can be represented by 8 bits, and is stored in the memory 1603, after being repeated n/8 times in order that the length of bits stored in memory 1603 equal the value of 'n'. A bit 1631 stored in the memory 1603 is the 0^{th} bit which is the most significant bit (MSB) of the CFN, and a bit 1638 is the 7^{th} bit which is the least significant bit (LSB) of the CNF. A bit 1639 stored in the memory 1603 is the MSB of the CFN and has the same value as the bit 1631, and a bit 163n is the LSB of the CFN and has the same value as the bit 1638. In the memory 1603 of FIG. 16, the order of the MSB and the LSB of the CFN can be changed.

A multiplier 1604 of FIG. 16 is comprised of n exclusive OR (XOR) operators 1641-164n. The multiplier 1604 performs an XOR operation on the n bits stored in the memory 1601 and the CFN bits stored in the memory 1603, and provides the operation results to a decimal converter 1605. That is, the n XOR operators 1641-164n XOR the bits 1611-161n output from the memory 1601 and the bits 1631-163n output from the memory 1603.

The decimal converter 1605 converts the operation results of the multiplier

1604 to a decimal number. That is, the decimal converter 1605 includes memories 1651-165n for storing n operation values output from the XOR operators 1641-164n of the multiplier 1604, and converts the operation values stored therein to a decimal number. A value of the decimal number is determined according to the value of 'n'. The decimal number output from the decimal converter 1605 is provided to a modulo operator 1607. The modulo operator 1607 outputs a value which depends on the DC value. For DC=1/3, the modulo operator 1607 outputs one of 0, 1 and 2. For DC=1/5, the modulo operator 1607 outputs one of 0, 1, 2, 3 and 4. The slots not to be transmitted in the gating slot group to which the output results of the modulo operator 1607 are applied, are determined based on the output results. The decimal converter 1605 and the modulo operator 1607 can also be implemented by software.

The descriptions of FIG. 15A and 16 can be expressed by Equation (1) below.

$$N(G,C^i)=\left(\sum_{l=0}^{15}\left(S\left(G_{prev}\times 2560\times\frac{1}{T}+G_{prev}+l\right)\oplus C^i_{(k \bmod 8)}\right)\times 2^{15-l}\right)\bmod T \qquad (1)$$

where, G : current gating slot group number,
G_{prev} : previous gating slot group number,
C^i : CFN number of ith frame ($=(C_0^iC_1^iC_2^iC_3^iC_4^iC_5^iC_6^iC_7^i)_2$), and
T : the reciprocal of the DC.
S: Scrambling code

For a better understanding of Equation (1), a description will be made of FIGS. 15A and 16 for the case where the present gating slot group is 1, n=16 , CFN= 10001100_2, and DC=1/3.

The 16-bit value '1101001010111000' of the scrambling code selected in the manner of FIG. 15A is stored in the memory 1601 of FIG. 16. Further, since CNF= 10001100, a value '1000110010001100' is stored in the memory 1603 of FIG. 16. The multiplier 1604 is comprised of 16 XOR operators, and outputs an XOR operation value '0101111000110100'. The decimal converter 1605 converts the

output value of the multiplier 1604 to a decimal value '11,386'(or '24,116'). For DC=3, the modulo operator 1607 performs a modulo-3 operation on the output value '11,386' (or '24,116') of the decimal converter 1605 and outputs a value 1 (or 2 in case of '24,116'). Therefore, out of 3 slots in the gating slot group #2, a second (or third) slot is transmitted for transmitting TFCI, TPC and pilot symbol which are control data on the DPDCH.

The descriptions of FIG. 15B and 16 can be expressed by Equation (2) below.

$$s(i,j)=\begin{cases}(A_j \oplus C_i)\bmod(S_G-1)+1, & j=0\\ (A_j \oplus C_i)\bmod S_G, & j=1,2,\ldots,N_G-2\,,\\ S_G-1, & j=N_G-1\end{cases} \qquad i=0,1,\ldots,255 \;\ldots.(2)$$

where, A_j : a sequence obtained by applying j bit offset to the fixed sequence A,
C_i : a sequence obtained by repeating current CFN,
S_G : the number of slots constituting one gating slot group, and
N_G : the number of gating slot groups constituting one frame.

A detailed description of Equation (2) will be made below.

In Equation (2), s(i,j) indicates a slot number, which should be transmitted, out of the slots constituting a jth gating slot group of an ith frame. Here, the slot number is not assigned in a frame unit, but assigned in a gating slot group unit. A_j indicates the n bit sequence obtained by applying a j offset to the fixed sequence A as shown in FIG 15B, where the amount of offset j is equal to each gating slot group number.C_i indicates an n-bit sequence created by repeating the current CFN (8 bits). The CFN is a connection frame number. The base station and the mobile station repeatedly count the CFN(0 to 255) starting at the beginning of the connection. S_G indicates the number of slots in one gating slot group. For DC=1/3, S_G is 3 and for DC=1/5, S_G is 5. N_G indicates the number of gating slot groups in one frame. For DC=1/3, N_G is 5, and for DC=1/5, N_G is 3. For j=0 (i.e., in the first gating slot group of the frame) A_0 and current CFN(C_i) are XORed and then '1' is added to a value

obtained by performing a modulo(S_G-1) operation on the XORed value. As the result of this operation, the first slot of every frame is always gated off (i.e., not transmitted). Further, for j=N_G-1 (i.e., in the last gating slot group of the frame), only the last slot S_G-1 is always gated on (i.e., transmitted). For the other gating slot groups ($0<j<N_G-1$), A_j and C_i are XORed and then a modulo-S_G operation is performed on the XORed value. The reason for processing the first and last gating slot groups differently from the other gating slot groups is to assist in channel estimation. FIG 15C shows the generation rule. It is also possible to determine the gating position using Equation (3) below in which the same rule is applied to every .

$$s(i,j) = (A_j \oplus C_i) \bmod S_G, \qquad j = 0,1,2,.,,,.N_G - 1, \qquad i = 0,1,...,255 \ldots (3)$$

An operation of determining the gating position of the slots in the gating slot group using Equations (2) and (3) will be described with reference to FIGS. 16, 10A and 10B.

The structure of FIG. 16 corresponds to the gating position selector 150 of FIG. 10A and the gating position selector 250 of FIG. 10B. An operation of the gating position selector will be described with reference to FIG. 16.

The memory 1601 stores the n bits selected in the manner described with reference to FIG. 15B, and 'n' is a multiple of 8, which is a positive number. Here, the sequence stored in the memory 1601 is a sequence A_j obtained by applying j bit offset to the fixed sequence A. A memory 1603 stores the repeated CFN, of n-bit length, which is equally used in the user equipment and every base station in communication with the user equipment. A sequence stored in the memory 1603 is a sequence C_i obtained by repeating the current CFN. The multiplier 1604 comprised of n XOR operators, performs an XOR operation on the sequence A_j and the sequence C_i stored in the memories 1601 and 1603 in a bit unit to generate the operation result of $A_j \oplus C_i$, and provides the operation result to the decimal converter 1605. The decimal converter 1605 converts the operation result of the multiplier 1604 to a decimal number, and provides the converted decimal value to the modulo operator 1607. The modulo operator 1607 outputs a value which depends on the number, S_G, of the slots constituting one gating slot group. That is, when S_G is 3 (i.e.,

DC=1/5), the modulo operator 1607 outputs 0, 1 and 2, and when S_G is 5 (i.e., DC=1/3), the modulo operator 1607 outputs 0, 1, 2, 3 and 4.

In addition, the modulo operator 1607 can perform the same modulo operation as shown in Equation (2) according to the gating slot group number in one frame. That is, if the present gating slot group has the first gating slot group number in the frame, the gating position is determined such that the first slot data in the first gating slot group should not be transmitted. Otherwise, if the present gating slot group has the last gating slot group number, the gating position is determined such that the last slot data in the last gating slot group should be always transmitted.

The determined gating position information of each gating slot group is provided to the gated transmission controller 141 of FIG. 10A or the gated transmission controller 241 of FIG. 10B. The gated transmission controller gates on the data on the DPCCH in the slot duration of the gating position determined by the gating position selector, and gates off the data on the DPCCH in the other slot duration.

In order for the base station and the mobile station to perform gated transmission, the mobile communication system has the following state transition methods, which are determined according to system setup. In one method, transition occurs by a set timer value or a transition command message from the base station. In another method, transition occurs sequentially while changing the gating rate. At this point, the gating rate DC can be determined in consideration of a capacity of the corresponding mobile station and the channel environments. Assume that one frame is comprised of 16 slots. Then, in the former transition method, a direct gating rate transition occurs from DC=1/1 to DC=1/2, from DC=1/1 to DC=1/4, or from DC=1/1 to DC=1/8. In the latter transition method, a sequential gating rate transition occurs from DC=1/1 to DC=1/2, from DC=1/2 to DC=1/4, and from DC=1/4 to 1/8. The gated transmission method according to an embodiment of the present invention will be described for both the case where one frame is comprised of 16 slots and the case where one frame is comprised of 15 slots. When one frame is comprised of 16 slots, the gating rate can become 1/2, 1/4 and 1/8, and when one frame is comprised of 15 slots, the gating rate can become 1/3 and 1/5.

FIGS. 7A and 7B show the uplink DPCCH for the case where a dedicated

MAC (Medium Access Control) logical channel is generated and a corresponding transition message is transmitted over the uplink DPDCH when there is no DPDCH data for a predetermined period of time of FIGS. 6A and 6B.

Reference numeral 311 of FIG. 7A shows a case where an uplink DPDCH message is generated while the uplink DPCCH does not undergo gated transmission (i.e., while the uplink DPCCH is continuously transmitted (DC=1/1)). Reference numeral 312 shows a case where the uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/2 gated transmission. Reference numeral 313 shows a case where the uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/4 gated transmission. Reference numeral 314 shows a case where the uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/8 gated transmission. Even for slots, which are not transmitted in the gated transmission pattern as shown by the reference numerals 312, 313 and 314, the slots in the corresponding duration undergo normal transmission when the uplink DPDCH is transmitted in the corresponding duration. In the slots for normal transmission, the TPC bits for downlink power control can be omitted and the pilot duration (or period) can be extended to a slot length before transmission. Beginning at the slots succeeding after transmitting the uplink DPDCH message by normal transmission of the slots, it is possible to transmit the uplink DPCCH without gating, or it is possible to continue the gated transmission at the original gating rate until a gating stop message is received from the base station. That is, when the uplink DPDCH message is transmitted during DC=1/2 gated transmission, it is possible to perform normal transmission on the slot of the above duration, thereafter perform DC=1/2 gated transmission again, and then stop gated transmission (DC=1) when transmitting user data after receiving a gating stop message from the base station.

As in the case of the uplink DPCCH, even for the slots which are not transmitted in the gated transmission pattern, the slots undergo normal transmission in the corresponding duration, when a downlink DPDCH message is generated during gated transmission for the downlink DPCCH. In the slots for normal transmission, the TPC bits for uplink power control can be omitted and the pilot duration can be extended to a slot length. Beginning at the slots succeeding after transmitting the downlink DPDCH message by normal transmission of the slots, it is possible to transmit the downlink DPCCH without gating, or it is possible to continue the gated transmission at the original gating rate until a gating stop request

message is received from the mobile station. That is, when the downlink DPDCH message is transmitted during DC=1/2 gated transmission, it is possible to perform normal transmission on the slot of the above duration, thereafter perform DC=1/2 gated transmission again, and then stop gated transmission (DC=1) when transmitting the user data after receiving a gating stop request message from the mobile station.

Reference numeral 315 of FIG. 7B shows a case where an uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/2 gated transmission. Reference numeral 316 shows a case where the uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/4 gated transmission. Reference numeral 317 shows a case where the uplink DPDCH message is generated while the uplink DPCCH undergoes DC=1/8 gated transmission. Even for the slots, which are not transmitted in the gated transmission pattern as shown by the reference numerals 315, 316 and 317, the slots in the corresponding duration undergo normal transmission when the uplink DPDCH is transmitted in the corresponding duration. In the slots for normal transmission, the TPC bits for downlink power control can be omitted and the pilot duration can be extended to a slot length before transmission. Beginning at the slots succeeding after transmitting the uplink DPDCH message by normal transmission of the slots, it is possible to transmit the uplink DPCCH without gating, or it is possible to continue the gated transmission at the original gating rate until a gating stop message is received from the base station. That is, when the uplink DPDCH message is transmitted during DC=1/2 gated transmission, it is possible to perform normal transmission on the slot of the above duration, thereafter perform DC=1/2 gated transmission again, and then stop gated transmission (DC=1) when transmitting user data after receiving a gating stop message from the base station.

It is also possible to simultaneously gate transmission of both the uplink DPCCH and the downlink DPCCH in the same gating pattern. Beginning at the slots succeeding after transmitting the downlink DPDCH message by normal transmission of the slots, generated while gating transmission of the downlink DPCCH, it is possible to transmit the downlink DPCCH without gating, or it is possible to gate transmission of the downlink DPCCH at the original gating rate until a gating stop message is received from the mobile station. That is, when the downlink DPDCH message is transmitted during DC=1/2 gated transmission, it is

possible to perform normal transmission on the slot of the above duration, thereafter perform DC=1/2 gated transmission again, and then stop gated transmission (DC=1) when transmitting the user data after receiving a gating stop message from the mobile station.

FIG. 8A shows a method for transmitting downlink and uplink signals when transmission of a downlink DPDCH is discontinued. When transmission of the downlink DPDCH is discontinued as shown by reference numeral 801 in the RBA mode where the uplink DPDCH has no traffic data to transmit, the base station and the mobile station start gating if a set timer value expires and a gating start message is received. Although FIG. 8A shows an embodiment where the gating start message is generated by the base station, it is also possible for the mobile station to send a gating-request message to the base station when there is no downlink and uplink DPDCH. While transmitting the downlink DPCCH in FIG. 8A, it is also possible to transmit all the TFCI, TPC and pilot symbols without gating. Since the TPC bits include meaningless TPC values determined by measuring power strength of the pilot symbols of the gated slots within the uplink DPCCH, the mobile station ignores the meaningless TPC values transmitted from the base station in order to perform uplink power control in consideration of the gating pattern for the uplink DPCCH, and performs transmission at the same transmission power as the transmission power for the previous slot.

Alternatively, while transmitting the downlink DPCCH in FIG. 8A, it is also possible to gate only the TFCI and TPC bits in the downlink DPCCH without gating the pilot symbols in the downlink DPCCH. At this point, the gating pattern is identical to a gating pattern for the uplink DPCCH of the mobile station. The slot, in which the TPC bits in the downlink DPCCH are gated, refers to the TPC bits generated by measuring the pilot symbols corresponding to the gated slot in the DPCCH transmitted from the mobile station.

Reference numeral 802 shows a situation where a message generated by the base station is transmitted to the mobile station over the downlink DPDCH. In this case, the mobile station, which has been gating transmission of the uplink DPCCH, can stop gated transmission and perform normal transmission (DC=1) after receiving the message. Alternatively, the mobile station, which has been gating transmission of the uplink DPCCH, can continue gated transmission even after receiving the

message, and then perform normal transmission (DC=1) upon receipt of a gating stop message.

FIG. 8B shows a method for transmitting downlink and uplink signals when transmission of an uplink DPDCH is discontinued. When transmission of the downlink DPDCH is discontinued as shown by reference numeral 803 in the RBA mode where there exists no downlink DPDCH, the base station and the mobile station make a state transition at a time point appointed (or scheduled) between them when a set timer value expires or after exchanging a state transition message. Although FIG. 8B shows an embodiment where the state transition message is generated through the downlink DPDCH, the state transition message can be generated even in the uplink DPDCH of the mobile station. While transmitting the downlink DPCCH of FIG. 8B, it is possible to transmit all the TFCI, TPC and pilot symbols without gating. Since the TPC bits include meaningless TPC values determined by measuring power strength of the pilot symbols of the gated slots within the uplink DPCCH, the mobile station ignores the meaningless TPC values transmitted from the base station in order to perform uplink power control in consideration of the gating pattern for the uplink DPCCH, and performs transmission at the same transmission power as the transmission power for the previous slot.

Alternatively, while transmitting the downlink DPCCH in FIG. 8B, it is also possible to gate only the TFCI and TPC bits in the downlink DPCCH without gating the pilot symbols in the downlink DPCCH. At this point, the gating pattern is identical to a gating pattern for the uplink DPCCH of the mobile station. The slot, in which the TPC bits in the downlink DPCCH are gated, refers to the TPC bits generated by measuring the pilot symbols corresponding to the gated slot in the DPCCH transmitted from the mobile station.

Reference numeral 804 shows a situation where a state transmission message generated by the base station is transmitted to the mobile station over the downlink DPDCH. In this case, the mobile station, which has been gating transmission of the uplink DPCCH, can stop gated transmission and perform normal transmission (DC=1) upon receipt of the state transition message. Alternatively, the mobile station, which has been gating transmission of the uplink DPCCH, can continue gated transmission even after receipt of the state transition message, and

then stop gated transmission and perform normal transmission (DC=1) at a state transition point designated by the state transition message.

FIG. 8C shows a method for transmitting downlink and uplink signals when transmission of a downlink DPDCH is discontinued. When transmission of the downlink DPDCH is discontinued as shown by reference numeral 805 in the RBA mode where there exists no uplink DPDCH, the base station and the mobile station transition to the RBS mode if a set timer value expires or a downlink DPDCH message for state transition is generated. Although FIG. 8C shows an embodiment where the message for state transition to the RBA mode is generated by the base station, it is also possible for the mobile station to send a state transition request message to the base station when there is no downlink and uplink DPDCH. While transmitting the downlink DPCCH in FIG. 8C, it is also possible to transmit all the TFCI, TPC and pilot symbols without gating. Since the TPC bits include meaningless TPC values determined by measuring the power strength of the pilot symbols of the gated slots within the uplink DPCCH, the mobile station ignores the meaningless TPC values transmitted from the base station in order to perform uplink power control in consideration of the gating pattern for the uplink DPCCH, and performs transmission at the same transmission power as the transmission power for the previous slot.

Alternatively, while transmitting the downlink DPCCH in FIG. 8C, it is also possible to gate only the TFCI and TPC bits in the downlink DPCCH without gating the pilot symbols in the downlink DPCCH. At this point, the gating pattern is identical to a gating pattern for the uplink DPCCH of the mobile station. The slot, in which the TPC bits in the downlink DPCCH are gated, refers to the TPC bits generated by measuring the pilot symbols corresponding to the gated slot in the DPCCH transmitted from the mobile station.

Reference numeral 806 shows a situation where a state transition message generated by the mobile station is transmitted to the base station over the uplink DPDCH. In this case, the mobile station, which has been gating transmission of the uplink DPCCH, can stop gated transmission and then perform normal transmission (DC=1) after transmission of the state transition message over the uplink DPDCH. Alternatively, the mobile station, which has been gating transmission of the uplink DPCCH, can continue gated transmission even after transmission of the state

transition message, and then stop gated transmission and perform normal transmission (DC=1) at the state transition point.

FIG. 8D shows a method for transmitting downlink and uplink signals when transmission of an uplink DPDCH is discontinued. When transmission of the uplink DPDCH is discontinued as shown by reference numeral 807 in the RBA mode where there exists no downlink DPDCH, the base station and the mobile station make a state transition at a time point appointed between them when a set timer value expires or after exchanging a state transition message. Although FIG. 8D shows an embodiment where the state transition message is generated through the downlink DPDCH, the state transition message can also be generated in the uplink DPDCH of the mobile station. While transmitting the downlink DPCCH in FIG. 8D, it is also possible to transmit all the TFCI, TPC and pilot symbols without gating. Since the TPC bits include meaningless TPC values determined by measuring power strength of the pilot symbols of the gated slots within the uplink DPCCH, the mobile station ignores the meaningless TPC values transmitted from the base station in order to perform uplink power control in consideration of the gating pattern for the uplink DPCCH, and performs transmission at the same transmission power as the transmission power for the previous slot.

Alternatively, while transmitting the downlink DPCCH in FIG. 8D, it is also possible to gate only the TFCI and TPC bits in the downlink DPCCH without gating the pilot symbols in the downlink DPCCH. At this point, the gating pattern is identical to a gating pattern for the uplink DPCCH of the mobile station. The slot, in which the TPC bits in the downlink DPCCH are gated, refers to the TPC bits generated by measuring the pilot symbols corresponding to the gated slot in the DPCCH transmitted from the mobile station.

Reference numeral 808 shows a situation where a state transition message generated by the mobile station is transmitted to the base station over the uplink DPDCH. In this case, the mobile station, which has been gating transmission of the uplink DPCCH, can stop gated transmission and then perform normal transmission (DC=1) after transmission of the state transition message over the uplink DPDCH. Alternatively, the mobile station, which has been gating transmission of the uplink DPCCH, can continue gated transmission even after transmission of the state transition message, and then stop gated transmission and perform normal

transmission (DC=1) at the state transition point.

FIG. 9A shows a method for transmitting downlink and uplink signals when transmission of a downlink DPDCH is discontinued. When transmission of the downlink DPDCH is discontinued, the base station and the mobile station make a state transition at a time point appointed between them if a set timer value expires or after exchanging a state transition message. FIG. 9A shows a case where the downlink DPCCH is gated in the same gating pattern as that of the uplink DPCCH. Although FIG. 9A shows an embodiment where the state transition message is transmitted through the downlink DPDCH, the state transition message can also be transmitted through the uplink DPDCH of the mobile station

FIG. 9B shows a method for transmitting downlink and uplink signals when transmission of an uplink DPDCH is discontinued. When transmission of the uplink DPDCH is discontinued, the base station and the mobile station make a state transition at a time point appointed between them if a set timer value expires or after exchanging a state transition message. FIG. 9B shows a case where a gating pattern for the downlink DPCCH is gated in the same gating pattern as that of the uplink DPCCH. Although FIG. 9B shows an embodiment where the state transition message is transmitted through the downlink DPDCH, the state transition message can also be transmitted through the uplink DPDCH of the mobile station.

In the foregoing drawings and descriptions, the downlink and uplink frames have the same frame starting point. However, in the UTRA (UMTS (Universal Mobile Telecommunications System) Terrestrial Radio Access) system, the starting point of the uplink frame is artificially delayed by 250μsec as compared with the starting point of the downlink frame. This is to make power control time delay become one slot (=0.625ms) in consideration of the propagation delay of the transmission signal when the cell radius is below 30km. Therefore, with due consideration of the artificial time delay between the downlink and uplink frame start time, the methods for gating transmission of the DPCCH signal are shown by FIGS. 11A to 11E. FIGS. 10A and 10B show structures of the base station transmitter and the mobile station transmitter, respectively, which enable such gated transmission.

FIG. 10A shows a structure of the base station transmitter according to

another embodiment of the present invention. The base station transmitter is different from FIG. 5A in that the pilot, TFCI and TPC bits constituting the downlink DPCCH can be separately gated in different gating patterns by the gated transmission controller 141. That is, the gated transmission controller 141 performs gated transmission on the pilot, TFCI and TPC bits for the downlink DPCCH at a slot (or time slot) scheduled with the mobile station in the RBS mode where the traffic data is not transmitted over the downlink and uplink DPDCHs. By using the gated transmission controller 141, it is also possible to assemble a pilot of an (n-1)th slot and TFCI and TPC bits of a nth slot in a gated transmission unit. When the base station transmits signaling data using the gated transmission controller 141 during gated transmission in the RBS mode, it is possible to avoid performing gated transmission on the pilot and TFCI in the duration where the signaling data is transmitted.

Alternatively, the gated transmission controller 141 can perform gated transmission on one slot (or one entire slot) including the pilot symbols, TFCI and TPC bits for the downlink DPCCH at a slot(or time slot) scheduled with the mobile station in the RBS mode where the traffic data is not transmitted over the downlink and uplink DPDCHs.

Although the downlink gating pattern is identical to the uplink gating pattern, there can exist an offset between them for efficient power control. The offset is given as a system parameter.

The gated transmission controller 141 can select the gating position of the slots either randomly or regularly according to the output of the gating position selector 250. That is, the gating position selector 250 can regularly determine the gating position of the slots. For example, for DC=1/3, 3^{rd}, 6^{th}, 9^{th}, . . . slots are transmitted (or gated on). Further, the gating position selector 250 can randomly select the gating position of the slots in the method described with reference to FIGS. 15A, 15B and 16. In this case, the positions of the slots to be gated are determined by the random pattern.

FIG. 10B shows a structure of the mobile station transmitter according to another embodiment of the present invention. The mobile station transmitter is different from FIG. 5B in that the pilot, TFCI, FBI and TPC bits constituting the

uplink DPCCH can be separately gated in the different patterns by the gated transmission controller 241. The gated transmission controller 241 gates transmission of the pilot, TFCI, FBI and TPC bits for the uplink DPCCH at a power control group (or time slot) scheduled with the mobile station in the RBS mode where the traffic data is not transmitted over the downlink and uplink DPDCHs. When the base station transmits signaling data using the gated transmission controller 241 during gated transmission in the RBS mode, it is possible to avoid performing gated transmission on the pilot and TFCI in the duration where the signaling data is transmitted.

Alternatively, the gated transmission controller 241 can perform gated transmission on one slot including the pilot symbols, TFCI, FBI and TPC bits for the uplink DPCCH at a slot scheduled with the mobile station in the RBS mode where the traffic data is not transmitted over the downlink and uplink DPDCHs.

Although the downlink gating pattern is identical to the uplink gating pattern, there can exist an offset between them for efficient power control. The offset is given as a system parameter.

The gated transmission controller 141 can select the gating position of the slots either randomly or regularly according to the output of the gating position selector 250. That is, the gating position selector 250 can regularly determine the gating position of the slots. For example, for DC=1/3, 3^{rd}, 6^{th}, 9^{th}, . . . slots are transmitted (or gated on). Further, the gating position selector 250 can randomly select the gating position of the slots in the method described with reference to FIGS. 15A, 15B and 16. In this case, the positions of the slots to be gated are determined by the random pattern.

FIGS. 11A to 11D and FIGS. 12A to 12E show signal transmission diagrams for gated transmission performed by the base station and the mobile station transmitters of FIGS. 10A and 10B. FIGS. 11A to 11D show how to perform gated transmission when the frame length is 10msec and each frame includes 16 slots, i.e., each slot has a length of 0.625msec. FIGS. 12A to 12E show how to perform gated transmission when the frame length is 10msec and each frame includes 15 slots, i.e., each slot has a length of 0.667msec.

FIG. 11A shows gated transmission for the downlink and uplink DPCCHs according to a first embodiment of the present invention. As shown in FIG. 11A, a gated transmission unit for the downlink DPCCH may not be a slot unit. That is, in two adjacent slots, a pilot symbol of an nth slot and TFCI and TPC bits of an (n+1)th slot are set as a gated transmission unit for the downlink DPCCH. For example, when the gating rate is 1/2, a pilot symbol of slot number 0 and TFCI and TPC bits of slot number 1 are set as a gated transmission unit for the downlink DPCCH. When the gating rate is 1/4, a pilot symbol of slot number 2 and TFCI and TPC bits of slot number 3 are set as a gated transmission unit for the downlink DPCCH. When the gating rate is 1/8, a pilot symbol of slot number 6 and TFCI and TPC bits of slot number 7 are set as a gated transmission unit for the downlink DPCCH. Here, the gated transmission unit for the downlink DPCCH is set to be different from the actual slot unit, since an nth pilot symbol may be required in the receiver to demodulate the (n+1)th TPC according to a demodulation method for the TPC signal.

When a signaling message is generated during such gated transmission, the signaling message is transmitted over the downlink or uplink DPDCH. Therefore, performance of the frame starting point is very important. In the invention, as shown in FIG. 11A, the TPC for the downlink DPCCH and the TPC for the uplink DPCCH are located at slot number 15 (i.e., the 16^{th} slot, which is the last slot of the nth frame), so that the first slot of the (n+1)th frame is power controlled using the TPC bits existing in the last slot of an nth frame. That is, the TPC for power controlling the first slot of the next frame is located at the last slot of the present frame.

Meanwhile, in the UTRA system stated above, an offset between the downlink and uplink frame start points is fixed to 250μsec. However, for gated transmission of the downlink and uplink DPCCHs, the offset value can be changed to an arbitrary value while the base station and the mobile station exchange a parameter for DPCCH gated transmission in the call setup process. The offset value is set to a proper value in consideration of propagation delay of the base station and the mobile station in the call setup process. That is, when the cell radius is over 30Km, the offset value can be set to a value larger than the conventional offset value of 250μsec for DPCCH gated transmission, and this value can be determined through experiments.

FIG. 11B shows gated transmission for the downlink and uplink DPCCHs according to a second embodiment of the present invention. FIG. 11B shows a case where transmission of the downlink DPCCH goes ahead of transmission of the uplink DPCCH during gated transmission, for the gating rates of 1/2, 1/4 and 1/8. This difference (i.e., offset) is designated by "DL-UL timing" for the gating rates of 1/2, 1/4 and 1/8.

Referring to FIG. 11B, in two adjacent slots, a pilot symbol of an nth slot and TFCI and TPC of the (n+1)th slot are set as a gated transmission unit for the downlink DPCCH. For example, for the gating rate 1/2, a pilot symbol of slot number 0 and TFCI and TPC of slot number 1 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/4, a pilot symbol of slot number 2 and TFCI and TPC of slot number 3 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/8, a pilot symbol of slot number 6 and TFCI and TPC of slot number 7 are set as a gated transmission unit for the downlink DPCCH.

In addition, it is noted that the TPC for power controlling the first slot of the next frame is located at the last slot of the present frame. That is, the TPC for the downlink DPCCH and the TPC for the uplink DPCCH are both located at slot number 15 (i.e., the 16^{th} slot).

FIG. 11C shows gated transmission for the downlink and uplink DPCCHs according to a third embodiment of the present invention. FIG. 11C shows a case where transmission of the uplink DPCCH goes ahead of transmission of the downlink DPCCH during gated transmission, for the gating rates of 1/2, 1/4 and 1/8.

Referring to FIG. 11C, in two adjacent slots, a pilot symbol of a predetermined nth slot and TFCI and TPC of the (n+1)th slot are set as a gated transmission unit for the downlink DPCCH. For example, for the gating rate 1/2, a pilot symbol of slot number 1 and TFCI and TPC of slot number 2 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/4, a pilot symbol of slot number 2 and TFCI and TPC of slot number 3 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/8, a pilot symbol of slot number 6 and TFCI and TPC of slot number 7 are set as a gated transmission unit for the downlink DPCCH.

In addition, it is noted that the TPC for power controlling the first slot of the next frame is located at the last slot of the present frame. That is, the TPC for the downlink DPCCH and the TPC for the uplink DPCCH are both located at a slot number 15 (i.e., the 16th slot).

FIG. 11D shows gated transmission for the downlink and uplink DPCCHs according to a fourth embodiment of the present invention. FIG. 11D shows a case where for the gating rates of 1/2, 1/4 and 1/8, transmission of the downlink DPCCH goes ahead of transmission of the uplink DPCCH during gated transmission, and the downlink and uplink gating patterns are set to the same period.

Referring to FIG. 11D, in two adjacent slots, a pilot symbol of the predetermined nth slot and TFCI and TPC of the (n+1)th slot are set as a gated transmission unit for the downlink DPCCH. For example, for the gating rate 1/2, a pilot symbol of slot number 0 and TFCI and TPC of slot number 1 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/4, a pilot symbol of slot number 0 and TFCI and TPC of slot number 1 are set as a gated transmission unit for the downlink DPCCH. For the gating rate 1/8, a pilot symbol of slot number 2 and TFCI and TPC of slot number 3 are set as a gated transmission unit for the downlink DPCCH.

In addition, it is noted that the TPC for power controlling the first slot of the next frame is located at the last slot of the present frame. That is, the TPC for the downlink DPCCH and the TPC for the uplink DPCCH are both located at slot number 15 (i.e., the 16th slot).

FIGS. 12A and 12B show gated transmission for the downlink and uplink DPCCHs according to a fifth embodiment of the present invention. FIGS. 12A and 12B show a case where a gating rate for gated transmission of the downlink and uplink DPCCHs is 1/3, i.e., gated on transmission is performed at the periods corresponding to 1/3 of the whole slots. That is, gated transmission is performed at the periods corresponding to 5 slots out of the whole 15 slots. At this point, a gated transmission unit for the downlink DPCCH is set to be different from a slot unit. That is, in two adjacent slots, a pilot symbol of the predetermined nth slot and TFCI and TPC of the (n+1)th slot are set as a gated transmission unit for the downlink

DPCCH. Accordingly, transmission is performed in the order of the pilot symbol of the nth slot and TPC and TFCI symbols of the (n+1)th slot.

In FIG. 12A, <Case 1> shows a case where the uplink DPCCH and the downlink DPCCH are simultaneously transmitted at the start of gated transmission, and the downlink and uplink gating patterns are set to the same period. With regard to two adjacent slots, a pilot symbol of slot number 1 and TFCI and TPC of slot number 2 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 4 and TFCI and TPC of slot number 5 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 7 and TFCI and TPC of slot number 8 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 10 and TFCI and TPC of slot number 11 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 13 and TFCI and TPC of slot number 14 are set as a gated transmission unit for the downlink DPCCH.

<Case 2> shows a case where transmission of the uplink DPCCH goes ahead of transmission of the downlink DPCCH at the start of gated transmission. At this point, with regard to two adjacent slots, a pilot symbol of slot number 0 and TFCI and TPC of slot number 1 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 3 and TFCI and TPC of slot number 4 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 6 and TFCI and TPC of slot number 7 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 9 and TFCI and TPC of slot number 10 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 12 and TFCI and TPC of slot number 13 are set as a gated transmission unit for the downlink DPCCH.

In FIG. 12B, <Case 3> shows a case where transmission of the uplink DPCCH goes ahead of transmission of the downlink DPCCH at the start of gated transmission. At this point, with regard to two adjacent slots, a pilot symbol of slot number 1 and TFCI and TPC of slot number 2 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 4 and TFCI and TPC of slot number 5 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 7 and TFCI and TPC of slot number 8 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 10 and

TFCI and TPC of slot number 11 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 13 and TFCI and TPC of slot number 14 are set as a gated transmission unit for the downlink DPCCH.

<Case 4> shows a case where transmission of the uplink DPCCH goes ahead of transmission of the downlink DPCCH at the start of gated transmission. At this point, with regard to two adjacent slots, a pilot symbol of slot number 14 and TFCI and TPC of slot number 0 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 2 and TFCI and TPC of slot number 3 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 5 and TFCI and TPC of slot number 6 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 8 and TFCI and TPC of slot number 9 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 11 and TFCI and TPC of slot number 12 are set as a gated transmission unit for the downlink DPCCH.

<Case 5> shows a case where transmission of the uplink DPCCH goes ahead of transmission of the downlink DPCCH at the start of gated transmission. At this point, with regard to two adjacent slots, a pilot symbol of slot number 0 and TFCI and TPC of slot number 1 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 3 and TFCI and TPC of slot number 4 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 6 and TFCI and TPC of slot number 7 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 9 and TFCI and TPC of slot number 10 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 12 and TFCI and TPC of a slot number 13 are set as a gated transmission unit for the downlink DPCCH.

FIG. 12C shows gated transmission for the downlink and uplink DPCCHs according to a sixth embodiment of the present invention. FIG. 12C shows a case where the gating rate for gated transmission of the downlink and uplink DPCCHs is 1/5, i.e., gated on transmission is performed so that 1/5 of the slots are transmitted in comparison to all the slots in standard transmission. That is, gated transmission is performed so that 3 slots out of the standard 15 slots are transmitted. At this point, a gated transmission unit for the downlink DPCCH is set to be different from a slot unit. That is, with regard to two adjacent slots, a pilot symbol of the predetermined

nth slot and TFCI and TPC of the (n+1)th slot are set as a gated transmission unit for the downlink DPCCH. Accordingly, the pilot symbol, TPC symbol and TFCI symbol are transmitted in 5 slots, and the symbols are transmitted in the order of the pilot symbol of the nth slot and the TPC and TFCI symbols of the (n+1)th slot. Here, the TPC symbol and the TFCI symbol are continuously transmitted.

Referring to FIG. 12C, with regard to two adjacent slots, a pilot symbol of slot number 3 and TFCI and TPC of slot number 4 are set as a gated transmission unit for the downlink DPCCH; a pilot symbol of slot number 8 and TFCI and TPC of slot number 9 are set as a gated transmission unit for the downlink DPCCH; and a pilot symbol of slot number 13 and TFCI and TPC of slot number 14 are set as a gated transmission unit for the downlink DPCCH.

FIG. 12D shows gated transmission for the downlink and uplink DPCCHs according to a seventh embodiment of the present invention. Referring to FIG. 12D, the gating pattern is set such that the last slot of the uplink DPCCH should not be gated in the RBS mode. Such a gating pattern has high channel estimation performance, since the base station can perform channel estimation using the pilot symbols in the last slot of the frame. In addition, it is possible to increase the time required when the base station processes the FBI bits transmitted from the mobile station.

FIG. 12E shows gated transmission for the downlink and uplink DPCCHs according to an eighth embodiment of the present invention. Shown is a gating pattern for transmitting a downlink message during gated transmission in the RBS mode.

Referring to FIG. 12E, for the frame period where the downlink message is transmitted (i.e., downlink DPDCH transmission period), gated transmission is discontinued for the pilot and TFCI, and only the TPC continues to undergo gated transmission according to the gating pattern. As illustrated in FIG. 12E, for the frame period where the uplink message is transmitted (i.e., uplink DPDCH transmission period), it is also possible to stop gating the pilot and TFCI, and continuously gate the FBI and TPC according to the gating pattern.

When the mobile communication system performs the gated transmission

function according to the present invention, it is necessary to be able to control transmission power of the DPCCH data even in the gated transmission state. Herein, a description will be made of operation in which the mobile station and the base station generate and transmit a TPC bit by measuring a signal received from the other party during gated transmission, and control transmission power of the data using the received TPC bit.

Gating of the DPCCH data is started and ended at the time indicated by the upper layer. In the gated transmission mode, the base station and the mobile station have the different operation according to whether there exists the DPDCH in the DPCH to be transmitted. When the DPDCH is not included in the DPCH, the gated transmission controller of the transmission side gates on data of the selected slot in the corresponding gating slot group and gates off data of the other slots by controlling the DPCCH data. Here, the method for determining the gating position of the slots in the gating slot group unit can be performed according to a predetermined gating pattern, or the gating position of the slots can also be determined in the irregular pattern using the SFN or CFN, as described above. Otherwise, when the DPDCH data is existed in the DPCH, the transmitter transmits (or gates on) every time slot. However, the receiving side recognizes only the slot in the selected gating position out of the slots of the received frame as a valid slot in term of power control. Such gated transmission can be applied either only to the downlink between the base station and the mobile station, or both to the uplink and the downlink. Power control is differently performed for the case where the gated transmission is applied only to the downlink and for the case where the gated transmission is applied both to the uplink and the downlink.

The uplink power control includes one method in which the base station generates a TPC (Transmit Power Control) bit by measuring a communication quality of the uplink, and another method in which the mobile station controls its transmission power according to the TPC bit transmitted from the base station over the downlink. The downlink power control includes one method in which the mobile station generates a TPC bit by measuring a communication quality of the downlink, and another method in which the base station controls its transmission power according to the TPC bit transmitted from the mobile station over the uplink. In describing the power control method during gated transmission, the time point when the TPC bit is generated and transmitted and the time point when the transmission

power is controlled using the received TPC bit will be described separately from the viewpoint of the base station and the mobile station.

First, a description will be made of a power control operation for the case where the gated transmission operation is performed both on the uplink and the downlink.

When the gated transmission operation is performed on the uplink and the downlink, since the slots which can be transmitted by the base station and the mobile station exist in an irregular pattern, power control should be performed considering the irregular pattern. FIGS. 17A and 17B show the power control time relationship when the gated transmission is performed on both the uplink and the downlink

Uplink Transmission Power Control of Mobile Station

The mobile station extracts TPC bits from the valid slot last received from the base station, i.e., from the gated-on slot of the downlink, and controls transmission power of its DPCCH data according to the value of the TPC bits. Here, since the valid slot of the downlink may be different from the valid slot of the uplink according to the type of the irregular gating pattern, the mobile station stores the received valid TPC bits and then transmits a transmittable slot, if any, according to the stored TPC bits.

TPC bit Generation and Transmission for Downlink Power Control

The mobile station generates a TPC bit by measuring the communication quality of the downlink during the valid (or gated-on) slot of the downlink. The generated TPC bit is stored before transmission, until the valid uplink slot is transmitted.

Downlink Transmission Power Control of Base Station

The base station extracts TPC bits from the valid slot last received from the mobile station, i.e., from the gated-on slot of the uplink, and controls its transmission power according to the value of the TPC bits. Here, since the valid slot of the uplink may be different from the valid slot of the downlink according to the

type of the irregular gating pattern, the mobile station stores the received valid TPC bits and then transmits a transmittable slot, if any, according to the stored TPC bits.

TPC Bit Generation and Transmission for Uplink Power Control

The base station generates a TPC bit by measuring the communication quality of the uplink during the valid slot of the uplink. The generated TPC bit is stored before transmission, until the valid downlink slot is transmitted.

Next, a description will be made of a power control operation for the case where the gated transmission is applied only to the downlink in the mobile communication system having the gated transmission function.

In the mobile communication system, when the gated transmission is applied only to the downlink, the mobile station continuously transmits the DPCCH data, whereas the base station transmits only the slot data in the gating position selected in the gating slot group unit. Therefore, the base station should perform a power control method being different from that for the case where the base station and the mobile station both perform the gated transmission, since the transmittable slots exist in the irregular pattern. FIGS. 18A and 18B show the power control time relationship for the case where the gated transmission is applied only to the downlink

Uplink Transmission Power Control of Mobile Station

The mobile station extracts TPC bits from the valid slot last received from the base station, i.e., from the slot in the gating position of the downlink selected in the gating slot group unit, and controls its transmission power according to the value of the TPC bits. Here, since the valid slot of the downlink may be different from the valid slot of the uplink according to the type of the irregular gating pattern, the mobile station stores the received valid TPC bits and then transmits a transmittable slot, if any, according to the stored TPC bits.

TPC Bit Generation and Transmission for Downlink Power Control

The mobile station generates a TPC bit by measuring the communication quality of the downlink during the valid slot of the downlink. The mobile station

immediately transmits the generated TPC bit to the base station, and repeatedly transmits the TPC bit until a new TPC bit is generated. The reason for repeatedly transmitting the TPC bit is because the base station receives at least one TPC bit until the slot where the base station can transmit the downlink, and it is possible to decrease a TPC error rate by repeated transmission.

Downlink Transmission Power Control of Base Station

The base station extracts TPC bits received from the mobile station and controls its transmission power according to the value of the TPC bits. Here, the base station can extract the TPC bits using at least one TPC bit repeatedly transmitted by the mobile station.

As described above, in the embodiment of the present invention, it is possible to control transmission power the base station and the mobile station not only for the case where the uplink DPCCH signal is gated and the downlink DPCCH signal is not gated or the downlink DPCCH signal is gated and the uplink DPCCH signal is not gated, but also for the case where both the uplink and downlink DPCCH data is gated.

As described above, the invention can increase system capacity by minimizing the time required in the sync reacquisition process of the base station, decreasing interference due to discontinuous transmission of the uplink DPCCH, increasing the mobile station battery life time, and decreasing interference due to transmission of the uplink TPC bits.

While the invention has been shown and described with reference to a certain preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A method for transmitting control data on a downlink channel in a base station for a mobile communication system, comprising the steps of:

determining whether the base station has downlink and uplink traffic channel data;

driving, if there is no traffic data for a predetermined time period, a random position selector to determine a random gating slot position;

gating on control data at the determined gating slot position; and

gating off control data in other slot positions.

2. The method as claimed in claim 1, wherein the channel data comprises a series of frames, each frame includes a plurality of slots, slots in each frame are divided into a plurality of gating slot groups, and each gating slot group has a determined gating slot position.

3. The method as claimed in claim 2, wherein the frame is comprised of 15 slots, the slot group is comprised of 5 slots, and the determined slot position is a randomized slot position out of the slots in the slot group.

4. The method as claimed in claim 2, wherein the frame is comprised of 15 slots, and each gating slot group is comprised of 3 slots.

5. The method as claimed in claim 2, wherein the random position selector determines the gating slot position by:

calculating a value x by multiplying a system frame number (SFN) of a immediately before the transmission by a specific integer;

selecting N bits, said N bits being selected starting from a position which is at an x-chip distance from a start point of a scrambling code of previous gating slot group ; and

determining a gating slot position of the each gating slot group by performing a modulo operation on the selected n bits, said modulo operation being by a number of slots in the gating slot group.

6. The method as claimed in claim 2, wherein the random position

selector determines the gating slot position using the following equation:

$$N(G,C^i)=\left(\sum_{l=0}^{15}\left(S\left(G_{prev}\times 2560\times\frac{1}{T}+G_{prev}+l\right)\oplus C^i_{(k \bmod 8)}\right)\times 2^{15-l}\right)\bmod T$$

where, G is a gating slot group number;

G_{prev} is a previous gating slot group number;

C^i is a Connection Frame Number (CFN) of an ith frame $(=(C_0^iC_1^iC_2^iC_3^iC_4^iC_5^iC_6^iC_7^i)_2)$; and

T is a reciprocal of the gating rate.

7. The method as claimed in claim 2, wherein the random position selector determines the gating slot position using the following equation except for the first gating slot group and last gating slot group:

$$s(i,j)=(A_j\oplus C_i)\bmod S_G,\qquad j=0,1,2,.,,,.N_G-1,\qquad i=0,1,...,255$$

where, A_j is a sequence obtained by applying j bit offset to a fixed sequence;

C_i ÷is a sequence obtained by repeating a Connection Frame Number (CFN);

S_G is a number of slots in one gating slot group; and

N_G is a number of gating slot groups in one frame.

8. The method as claimed in claim 7, wherein the random position selector determines the gating slot position of the first gating slot group except for the first slot.

9. The method as claimed in claim 8, wherein the random position selector determines the gating slot position of the last gating slot group as the last slot.

10. The method as claimed in claim 2, wherein the gating on control data includes a pilot symbol and a TPC (Transmit Power Control) bit.

11. The method as claimed in claim 2, wherein the gating on control data includes a TPC (Transmit Power Control) bit located in the determined gating slot position and a pilot symbol located in a slot previous to the determined gating slot position.

12. The method as claimed in claim 1, wherein the base station transmits, if there is no data on the downlink and uplink traffic channel for the predetermined time period, gating information includes a gating start time and a gating rate.

13. A method for transmitting control data on an uplink channel in a mobile station for a mobile communication system, comprising the steps of:

determining whether the mobile station has uplink traffic channel data to transmit to a base station;

transmitting, if there is no data to be transmitted over the uplink data channel for a predetermined time period, a request for gating uplink control data to the base station;

driving, when the mobile station receives gating information including gating start time and gating rate from the base station, a random position selector to determine a random gating slot position;

gating on control data in the determined slot position; and

gating off control data in other slot positions.

14. A method for gating data using a plurality of slots in an ith frame in a stream of frames, wherein each frame includes a plurality of slots and the slots in each frame are divided into a plurality of gating slot groups, each gating slot group including a plurality of slots, the method comprising the step of:

transmitting data in a slot position determined by Equations (1)-(3) below,

$$s(i,j) = \begin{cases} (A_j \oplus C_i) \bmod (S_G - 1) + 1, & j = 0 & & (1) \\ (A_j \oplus C_i) \bmod S_G, & j = 1,2,\ldots,N_G - 2, & i = 0,1,\ldots,255 & (2) \\ S_G - 1, & j = N_G - 1 & & (3) \end{cases}$$

where j is a number of a gating slot group in the ith frame;

where C_i is a sequence obtained by repeating a ith connection frame number(CFN); and

where A_j is a sequence associated with a jth gating slot group, said sequence obtained by applying j bit offset to a given sequence;

where S_G is a number of slots in one gating slot group; and

where N_G is a number of gating slot groups in one frame .

15. A method for gating data using a plurality of slots in an ith frame in a stream of frames, wherein each frame includes a plurality of slots and the slots in each frame are divided into a plurality of gating slot groups, each gating slot group including a plurality of slots, the method comprising the steps of:

determining a gating slot position of gating slot groups using the gating slot position formula below:

$$s(i,j) = (A_j \oplus C_i) \bmod S_G, \qquad j = 0,1,2,.,,,.N_G - 1$$

where s(i,j) is a slot position within a jth gating slot group in a ith frame;

where j is a number of a gating slot group in an ith frame;

where C_i is a sequence obtained by repeating the ith frame number(CFN); and

where A_j is a sequence associated with a jth gating slot group, said sequence obtained by applying j bit offset to a given sequence;

gating on Transmit Power Control (TPC) bit at the determined gating slot position; and

gating off the TPC bit at other slots.

16. The method as claimed in claim 15, wherein the gating on step comprises the steps of:

gating on the TPC bit at the determined gating slot position ; and

gating on a pilot symbol at a slot located before the determined gating slot position.

17. The method as claimed in claim 15, wherein the gating slot position determination step further comprises the step of:

determining a gating slot position in a first gating slot group of an ith frame by using a formula below:

$$s(i,j) = (A_j \oplus C_i) \mathrm{mod}(S_G - 1) + 1, \qquad \mathrm{j} = 0 \qquad i = 0,1,\ldots,255$$

18. The method as claimed in claim 15, wherein the gating slot position determination step further comprises the step of:

determining a gating slot position in a last gating slot group of an ith frame as last slot.

19. A method for transmitting gated transmission of uplink dedicated physical control channel(DPCCH) data which is formed by series of frames, the frame includes plurality of slots, for a mobile communication system, comprising the steps of:

receiving a gating information indicating gating start time and gating rate from a base station;

transmitting the DPCCH slot signal to form a random pattern for a predetermined duration.

20. A method as claimed in claim 19, wherein the random pattern is generated by determining gating on slot position using bellow equation;

$$s(i,j) = \begin{cases} \left(A_j \oplus C_i\right)\bmod(S_G - 1) + 1, & j = 0 & & (1) \\ \left(A_j \oplus C_i\right)\bmod S_G, & j = 1,2,\ldots,N_G - 2, & i = 0,1,\ldots,255 & (2) \\ S_G - 1, & j = N_G - 1 & & (3) \end{cases}$$

where, where j is a number of a gating slot group in the ith frame;

where C_i is a sequence obtained by repeating the ith frame number; and

where A_j is a sequence obtained by applying j bit offset to a given sequence;

where S_G is a number of slots in one gating slot group; and

where N_G is a number of gating slot groups in one frame .

21. A base station transmitter in a mobile communication system, in which traffic channel data and dedicated physical control channel (DPCCH) data each are comprised of a series of frames, and each frame includes a plurality of slots, comprising:

a gating position selector for determining a gating slot position when there is no data to transmit on the traffic channel for a predetermined time period, and for dividing the slots in each frame into a plurality of gating slot groups, each of said gating slot groups having a random gating slot position;

a gated transmission controller for controlling a DPCCH slot corresponding

to the selected gating slot position.

22. The base station transmitter as claimed in claim 21, wherein the gating position selector determining the gating slot positionby using formulas (1)-(3) below:

$$s(i,j)=\begin{cases}(A_j \oplus C_i)\bmod(S_G-1)+1, & j=0 & & (1)\\ (A_j \oplus C_i)\bmod S_G, & j=1,2,\ldots,N_G-2, & i=0,1,\ldots,255 & (2)\\ S_G-1, & j=N_G-1 & & (3)\end{cases}$$

where j is a number of a gating slot group in the ith frame;
where C_i is a sequence obtained by repeating the ith frame number (CFN=i); and
where A_j is a sequence associated with a jth gating slot group, said sequence obtained by applying j bit offset to a given sequence;
where S_G is a number of slots in one gating slot group; and
where N_G is a number of gating slot groups in one frame.

23. The base station transmitter as claimed in claim 21, wherein the gating position selector determining the gating slot positionby using a formula below:

$$s(i,j)=(A_j \oplus C_i)\bmod S_G, \qquad j=0,1,2,.,,,.N_G-1, \qquad i=0,1,\ldots,255$$

where s(i,j) is a slot position within a jth gating slot group in a ith frame;
where j is a number of a gating slot group in the ith frame;
where C_i is a sequence obtained by repeating the ith frame number; and
where A_j is a sequence associated with a jth gating slot group in the ith frame, said sequence obtained by applying j bit offset to a given sequence.

24. The base station transmitter as claimed in claim 21, wherein the gating position selector determining the gating slot positionby using a formula below:

$$s(i,j) = (A_j \oplus C_i)\mathrm{mod}(S_G - 1) + 1, \qquad j = 0 \qquad i = 0,1,\ldots,255$$

where s(i,j) is a slot position within a jth gating slot group in a ith frame;

where j is a number of a gating slot group in the ith frame;

where C_i is a sequence obtained by repeating the ith frame number; and

where A_j is a sequence associated with the jth gating slot group, said sequence obtained by applying j bit offset to a given sequence.

25. The base station transmitter as claimed in claim 21, wherein the gating position selectordetermining the gating slot positionby using a formula below:

$$s(i,j) = S_G - 1, \qquad j = N_G - 1, \qquad i = 0,1,\ldots,255$$

where s(i,j) is a slot position within a jth gating slot group in a ith frame;

where j is a number of a gating slot group in the ith frame;

where C_i is a sequence obtained by repeating the ith frame number; and

where A_j is a sequence associated with a jth gating slot group, said sequence obtained by applying j bit offset to a given sequence.

26. The base station transmitter as claimed in claim 22, wherein the gated transmission controller gates on a pilot symbol at a slot located before a determined gating slot, and gates on at least one Transmit Power Control (TPC) bit and at least one Transport Format Combination Indicator (TFCI) bit at the determined gating slot.

27. A mobile station transmitter in a mobile communication system, in which traffic channel data and dedicated physical control channel (DPCCH) data each includes a series of frames, and each frame includes a plurality of slots, comprising:

a gating slot position selector for determining a gating slot position when the mobile station receives gating information includes gating start time and gating rate

form a base station, and dividing the slots in each frame into a plurality of gating slot groups, each of said gating slot groups having the gating slot position;

a gated transmission controller for gating on at the determined gating slot position and gating off the other slot signal in a gating slot group.

28. An apparatus for gating data of a plurality of slots in an ith frame in a series of frames, wherein each frame includes a plurality of slots and the slots in each frame are divided into a plurality of gating slot groups, each gating slot group including a plurality of slots, the apparatus comprising:

a first memory for storing a sequence C_I, said sequence obtained by repeating the ith frame number;

a second memory for storing a sequence A_j associated with a jth gating slot group, said sequence A_j obtained by a given sequence;

a multiplier for performing an exclusive-or operation on the sequences C_i and A_j;

a modulo operator for performing a modulo operation on an output of the multiplier, said modulo operation being by a number of slots in a gating slot group, where the result is a gating slot position in the jth gating slot group; and

a gated transmission controller for gating on the data in the determined gating slot position and gating off the other slot data in the gating slot group.

29. The apparatus as claimed in claim 28, wherein the gated transmission controller transmits Transmit Power Control (TPC) bit at the determined gating slot position, and a pilot symbols of a slot located before the determined gating slot position.

30. The apparatus as claimed in claim 27, wherein the modulo operator determines the gating slot position of the first gating slot groupas one of the slot in the first gating slot group except for the first slot.

31. The apparatus as claimed in claim 28, wherein the modulo operator determines the gating positionof the last gating slot group as last slot.

FIG. 1A

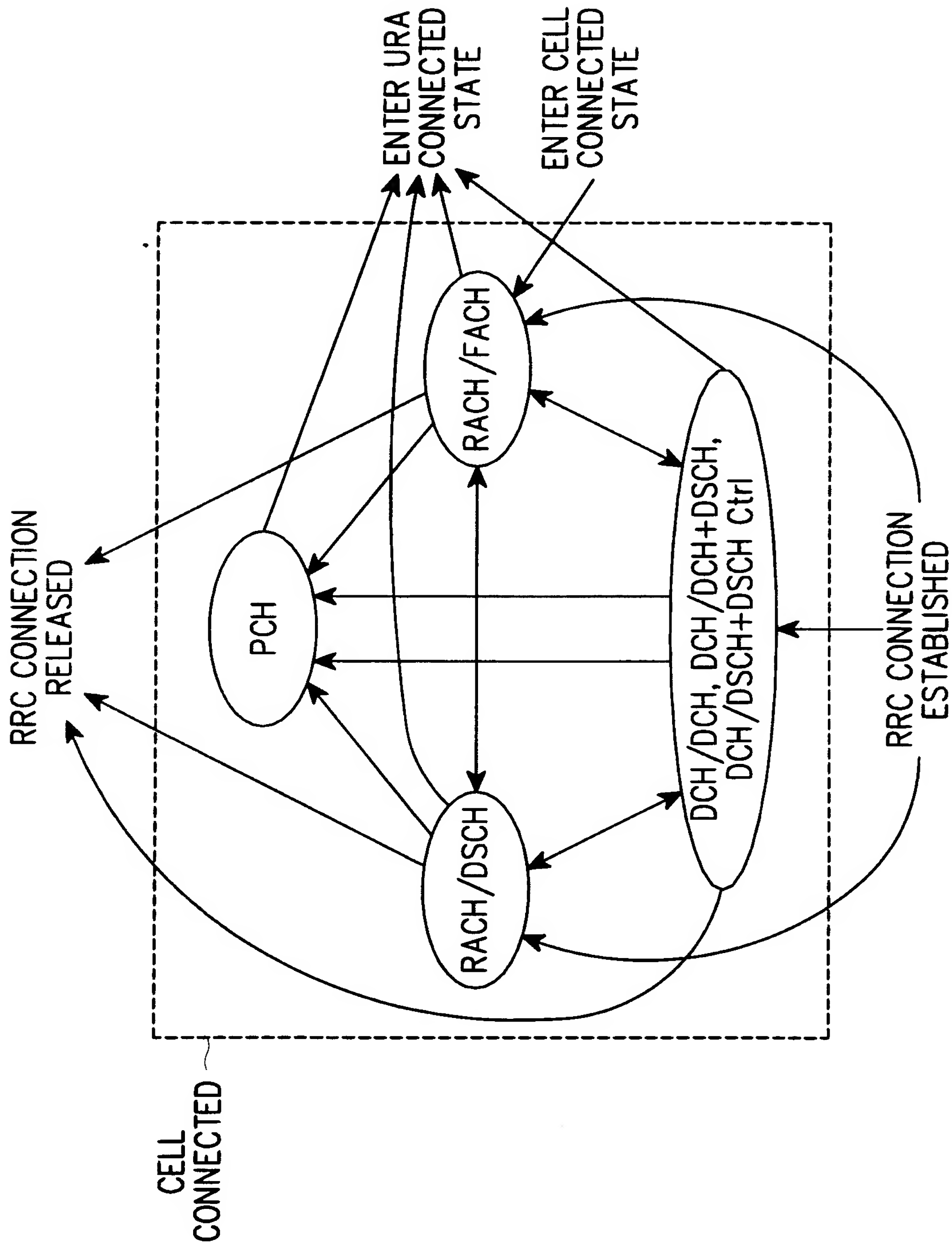

RRC CONNECTION RELEASED
ENTER URA CONNECTED STATE
ENTER CELL CONNECTED STATE
PCH
RACH/FACH
RACH/DSCH
DCH/DCH, DCH/DCH+DSCH, DCH/DSCH+DSCH Ctrl
RRC CONNECTION ESTABLISHED
CELL CONNECTED

FIG. 1B

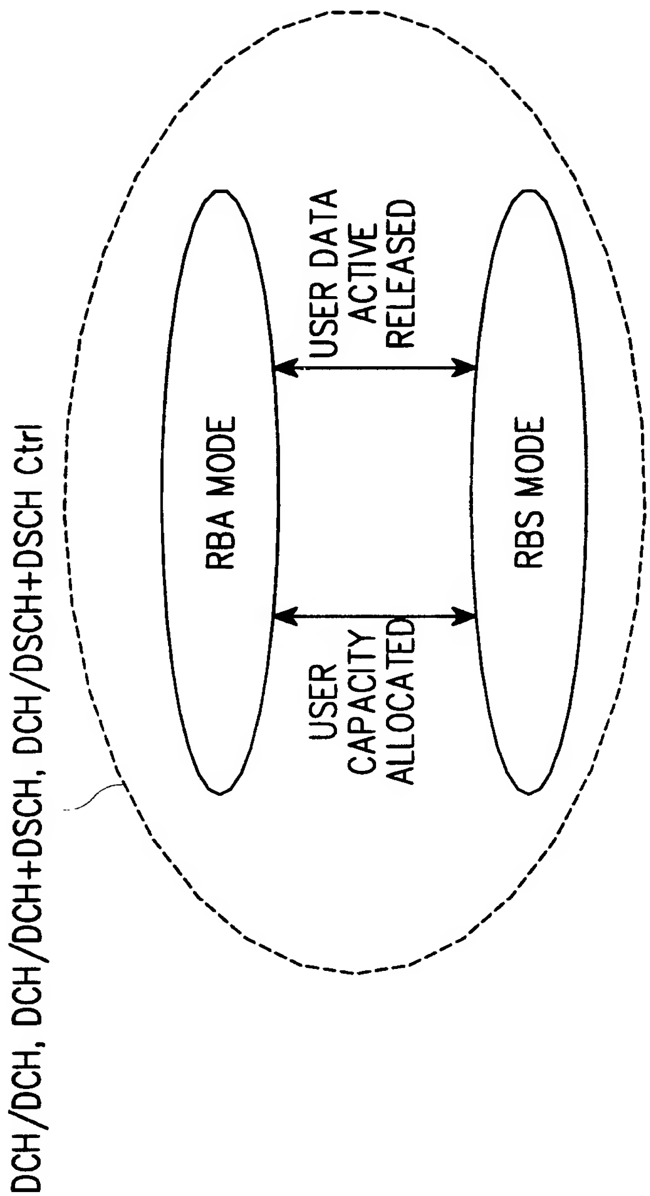

DCH/DCH, DCH/DCH+DSCH, DCH/DSCH+DSCH Ctrl
RBA MODE
RBS MODE
USER DATA
ACTIVE
RELEASED
USER
CAPACITY
ALLOCATED

FIG. 2A

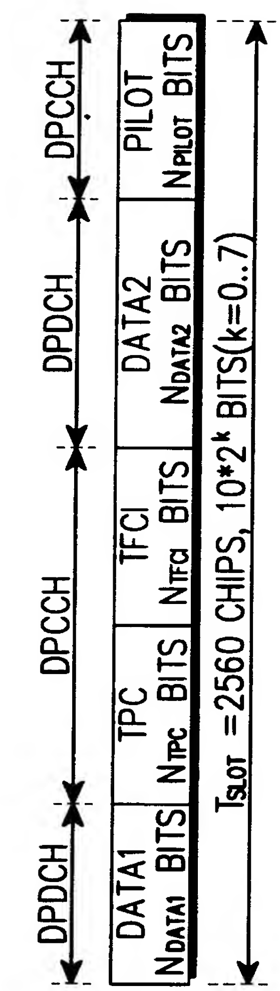

DPDCH
DPCCH
DPDCH
DPCCH
DATA1 N_{DATA1} BITS
TPC N_{TPC} BITS
TFCI N_{TFCI} BITS
DATA2 N_{DATA2} BITS
PILOT N_{PILOT} BITS
T_{SLOT} =2560 CHIPS, $10*2^k$ BITS(k=0..7)

FIG. 2B

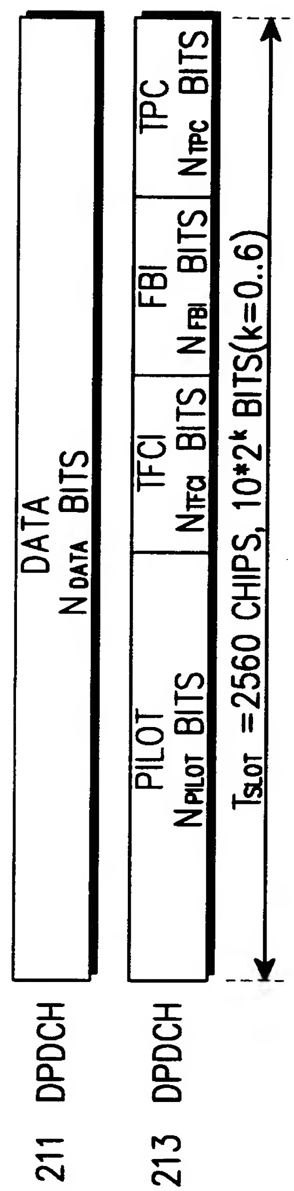

211 DPDCH
213 DPDCH
DATA N_{DATA} BITS
PILOT N_{PILOT} BITS
TFCI N_{TFCI} BITS
FBI N_{FBI} BITS
TPC N_{TPC} BITS
T_{SLOT} =2560 CHIPS, $10*2^k$ BITS(k=0..6)

FIG. 3A

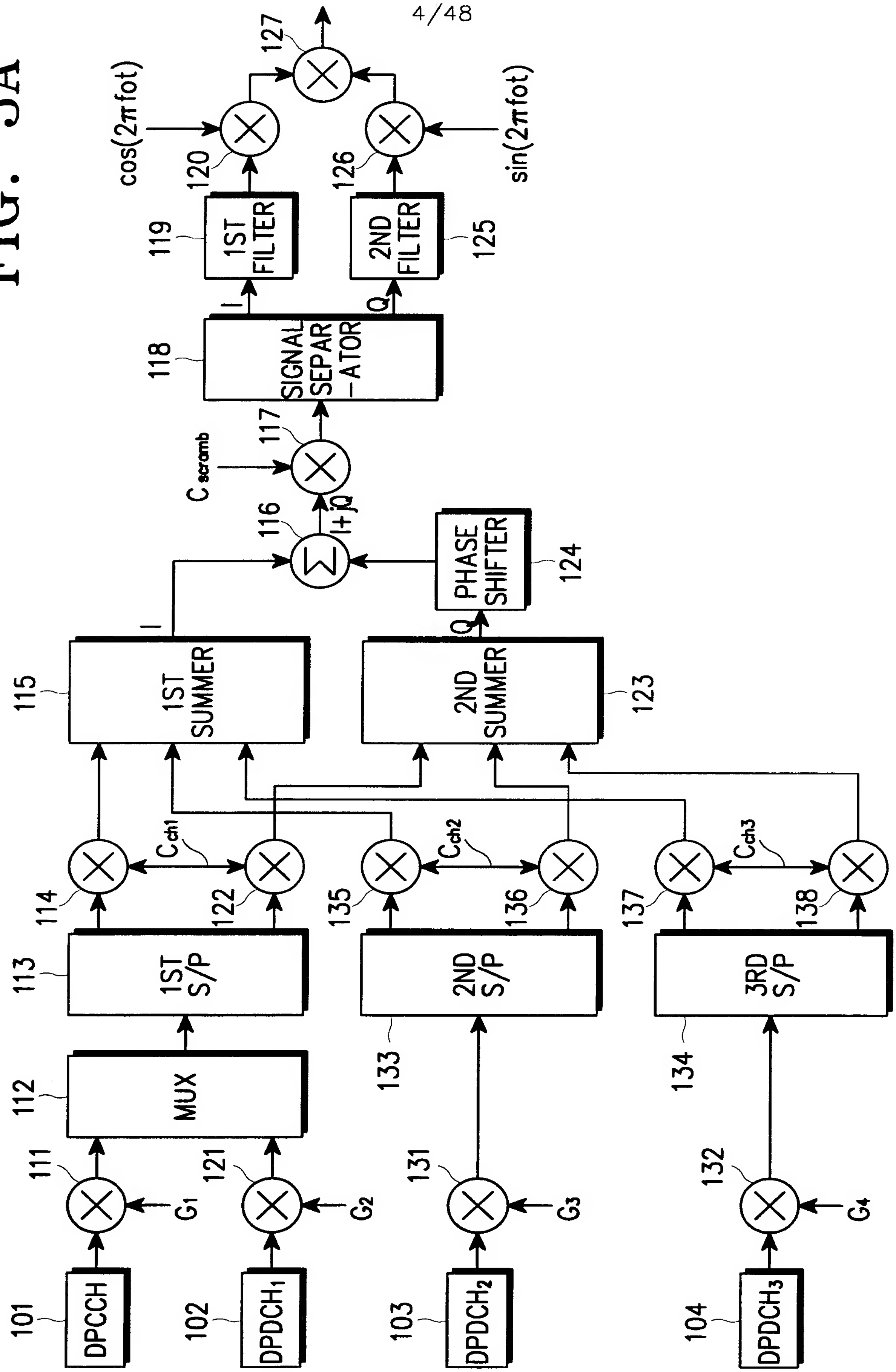

DPCCH
DPDCH1
DPDCH2
DPDCH3
G1
G2
G3
G4
MUX
1ST S/P
2ND S/P
3RD S/P
Cch1
Cch2
Cch3
1ST SUMMER
2ND SUMMER
I
Q
PHASE SHIFTER
I+jQ
C scramb
SIGNAL SEPAR -ATOR
1ST FILTER
2ND FILTER
cos(2πfot)
sin(2πfot)
101
102
103
104
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
131
132
133
134
135
136
137
138

FIG. 3B

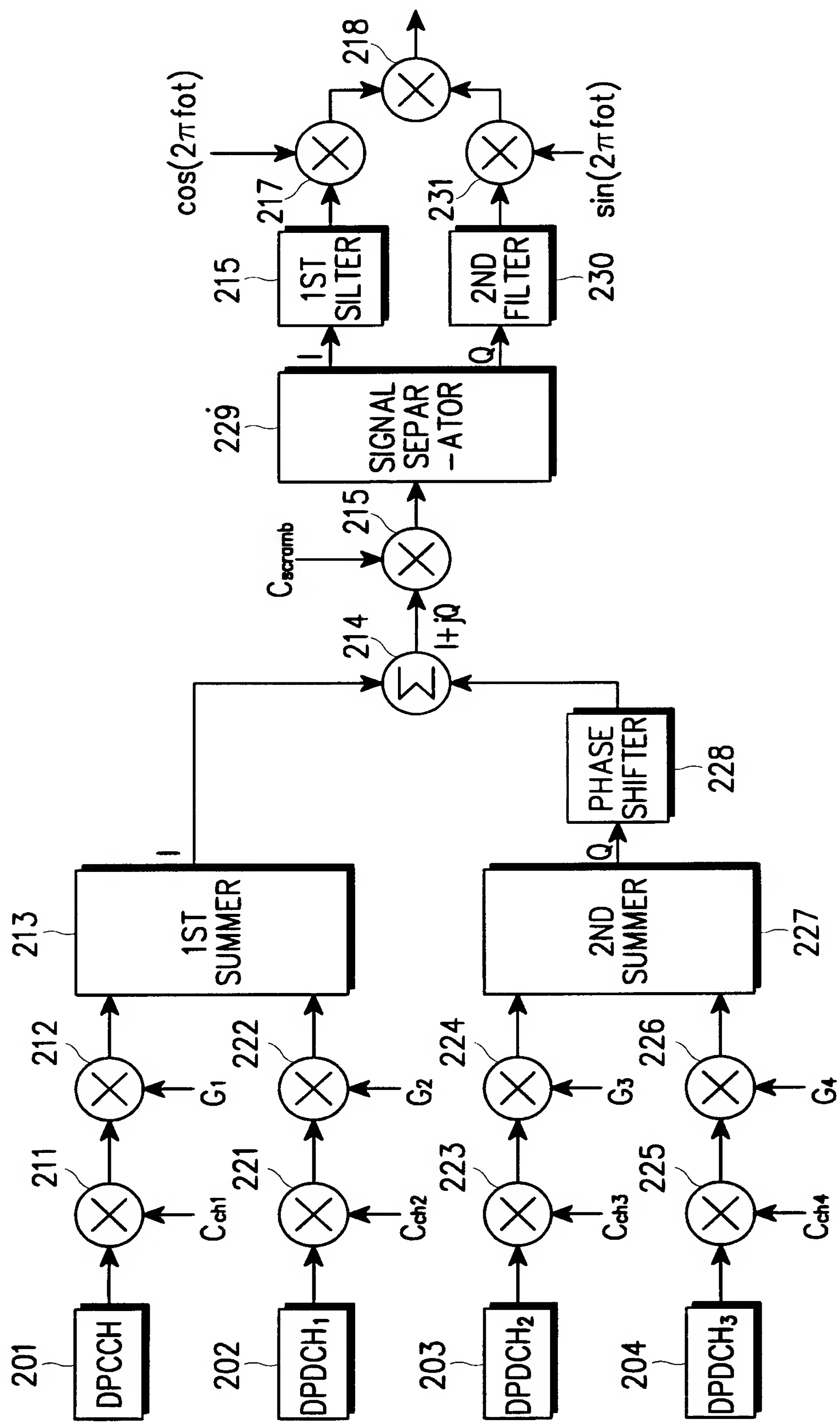

DPCCH
DPDCH1
DPDCH2
DPDCH3
201
202
203
204
211
212
221
222
223
224
225
226
Cch1
Cch2
Cch3
Cch4
G1
G2
G3
G4
1ST SUMMER
2ND SUMMER
213
227
I
Q
PHASE SHIFTER
228
214
I+jQ
Cscramb
215
SIGNAL SEPAR -ATOR
229
I
Q
1ST SILTER
2ND FILTER
215
230
217
231
cos(2πfot)
sin(2πfot)
218

FIG. 4A

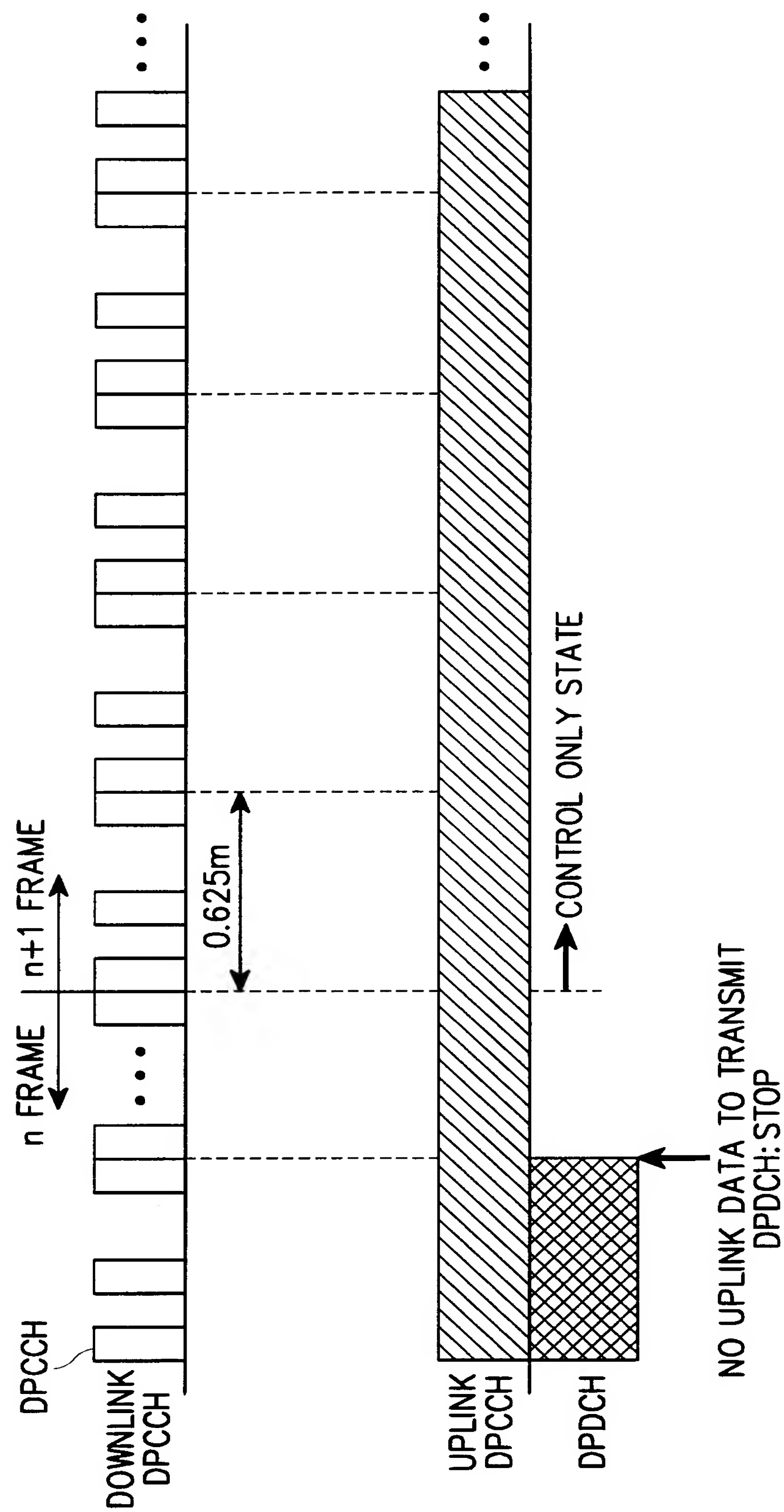

DPCCH
DOWNLINK DPCCH
n FRAME
n+1 FRAME
0.625m
UPLINK DPCCH
DPDCH
CONTROL ONLY STATE
NO UPLINK DATA TO TRANSMIT
DPDCH:STOP

FIG. 4B

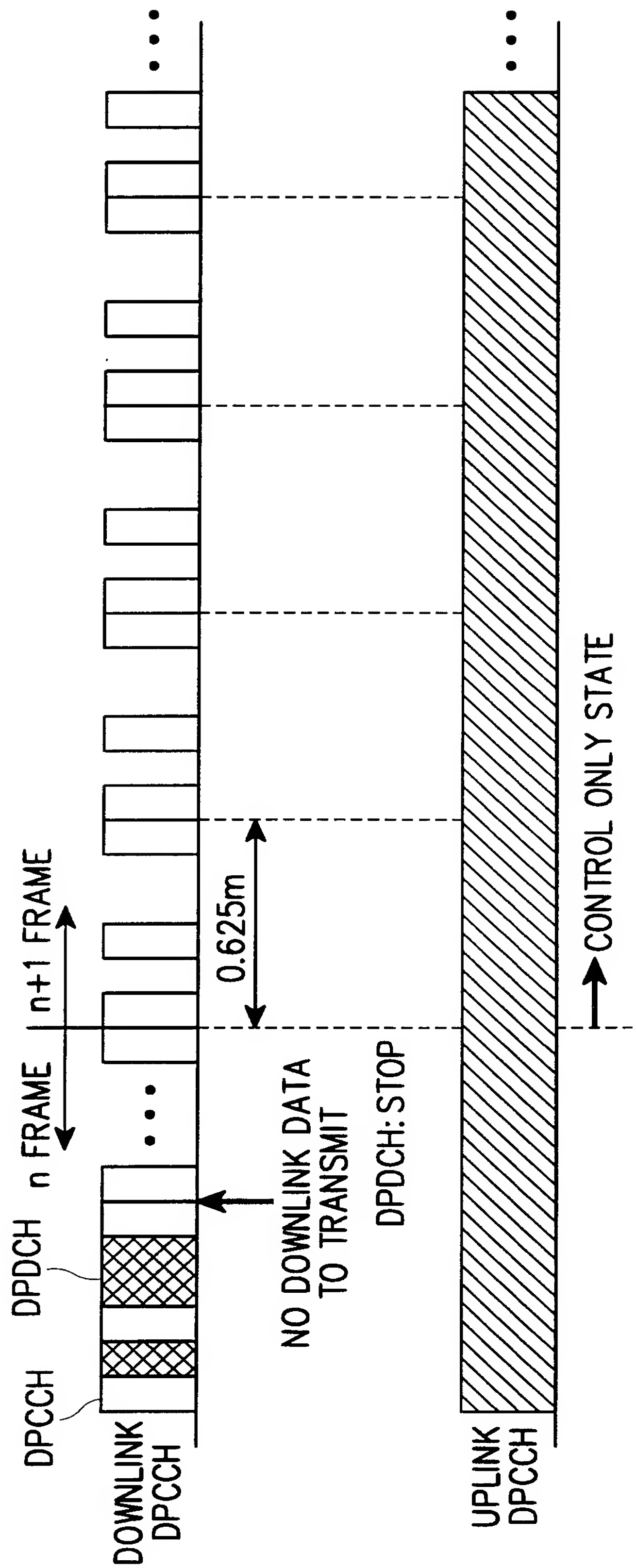

DOWNLINK DPCCH
DPCCH
DPDCH
n FRAME
n+1 FRAME
NO DOWNLINK DATA TO TRANSMIT
DPDCH:STOP
0.625m
UPLINK DPCCH
CONTROL ONLY STATE

FIG. 5A

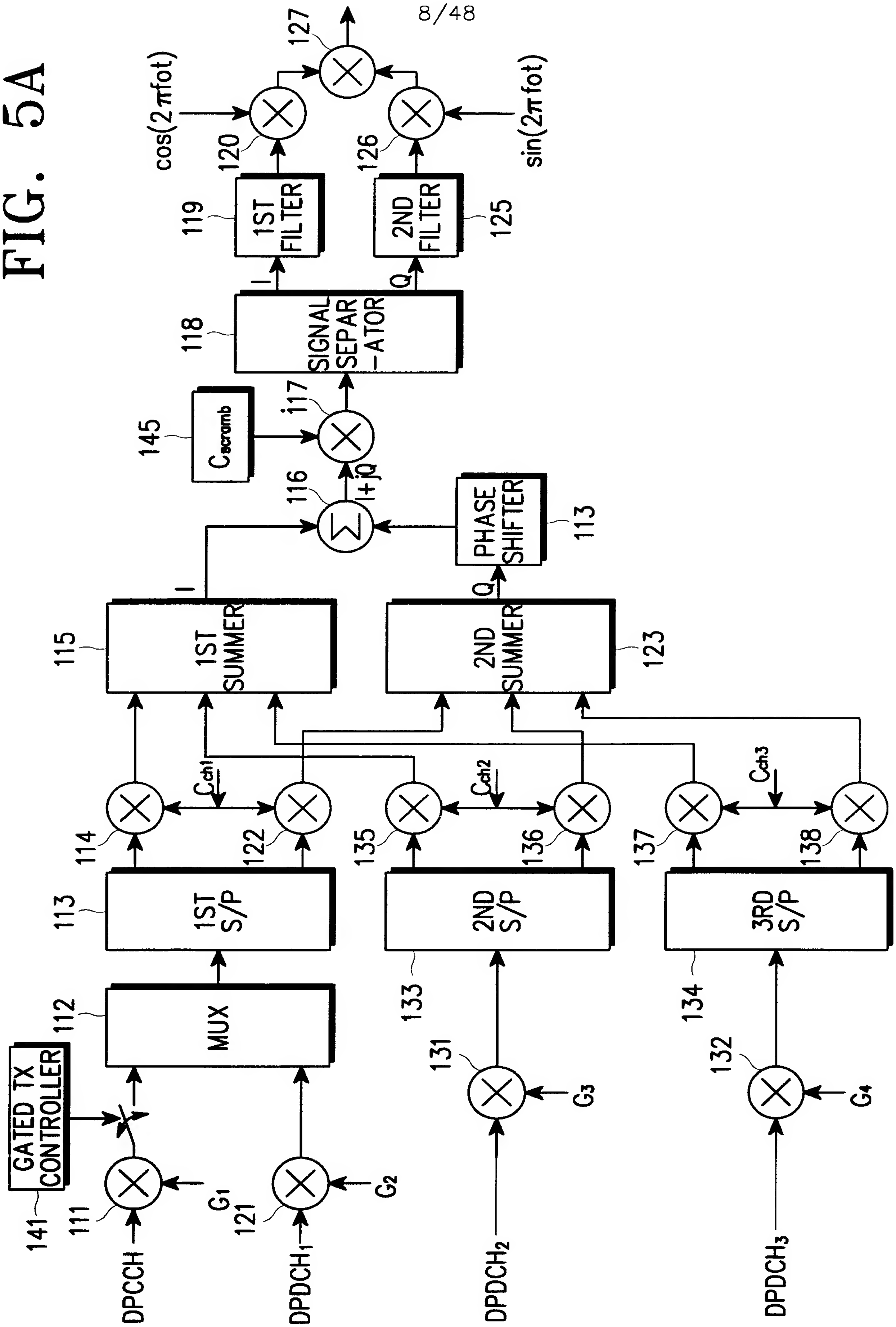

GATED TX CONTROLLER
141
DPCCH
111
G1
DPDCH1
121
G2
DPDCH2
131
G3
DPDCH3
132
G4
MUX
112
1ST S/P
113
2ND S/P
133
3RD S/P
134
114
122
135
136
137
138
Cch1
Cch2
Cch3
1ST SUMMER
115
2ND SUMMER
123
I
Q
PHASE SHIFTER
113
116
I+jQ
Cscramb
145
117
SIGNAL SEPAR -ATOR
118
1ST FILTER
119
2ND FILTER
125
120
126
cos(2πfot)
sin(2πfot)
127

FIG. 5B

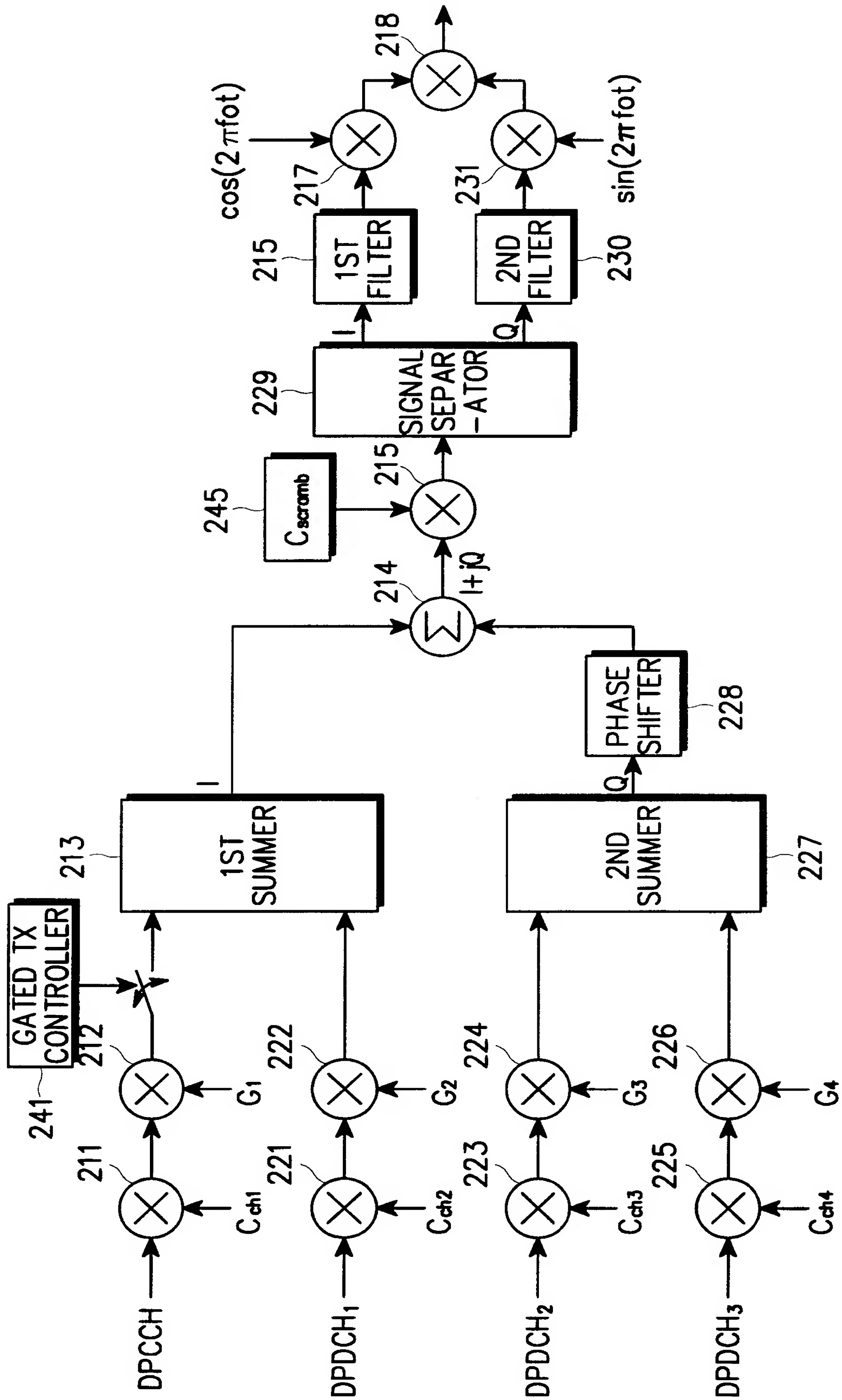

DPCCH
DPDCH1
DPDCH2
DPDCH3
211
221
223
225
Cch1
Cch2
Cch3
Cch4
212
222
224
226
G1
G2
G3
G4
241
GATED TX CONTROLLER
213
1ST SUMMER
227
2ND SUMMER
I
Q
PHASE SHIFTER
228
214
I+jQ
245
Cscramb
215
229
SIGNAL SEPAR -ATOR
I
Q
215
1ST FILTER
230
2ND FILTER
217
231
cos(2πfot)
sin(2πfot)
218

FIG. 5C

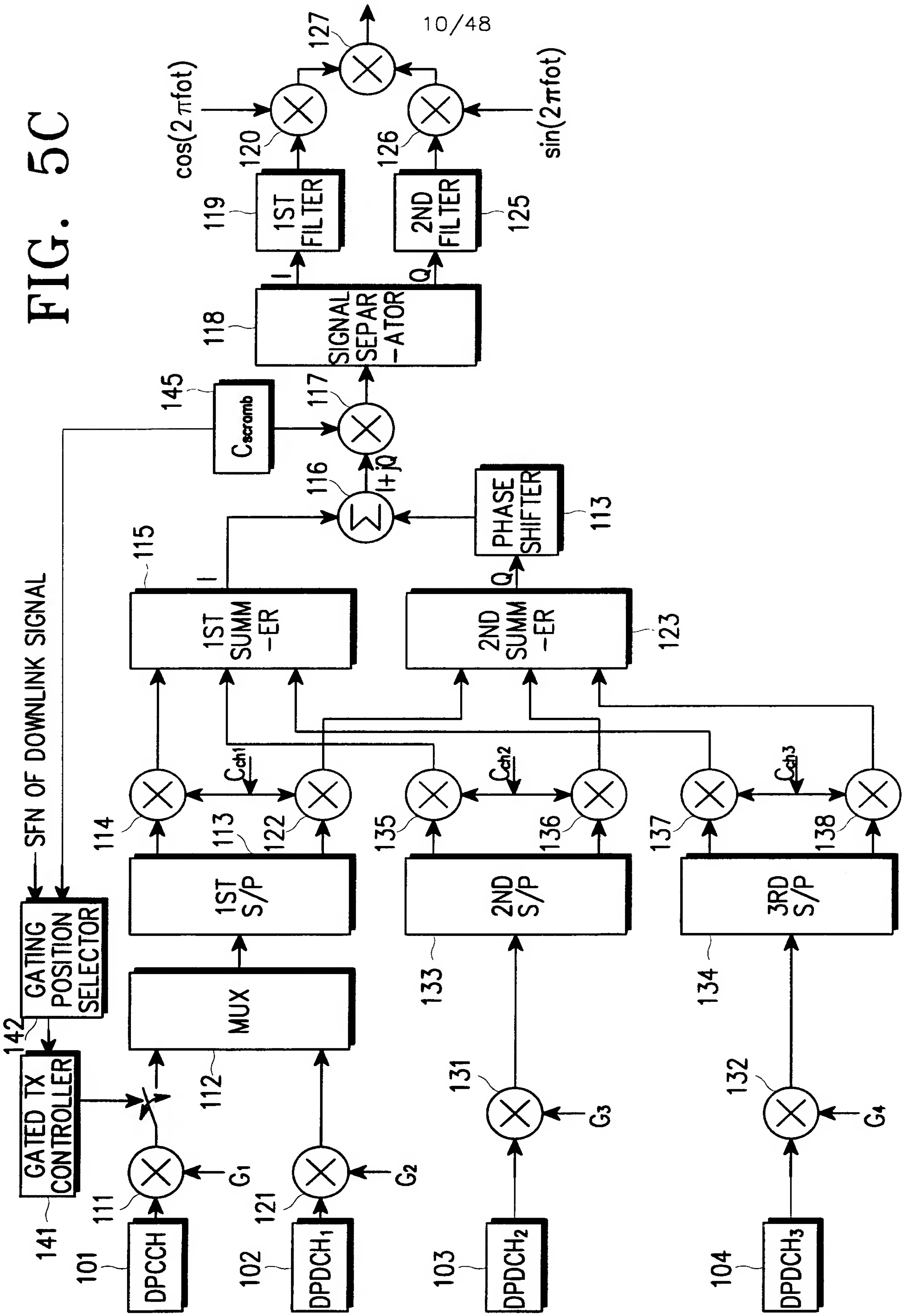

DPCCH
DPDCH1
DPDCH2
DPDCH3
GATED TX CONTROLLER
GATING POSITION SELECTOR
SFN OF DOWNLINK SIGNAL
MUX
1ST S/P
2ND S/P
3RD S/P
1ST SUMM -ER
2ND SUMM -ER
PHASE SHIFTER
Cscramb
SIGNAL SEPAR -ATOR
1ST FILTER
2ND FILTER
cos(2πfot)
sin(2πfot)
I+jQ
I
Q
G1
G2
G3
G4
Cch1
Cch2
Cch3
101
102
103
104
111
112
113
114
115
116
117
118
119
120
121
122
123
125
126
127
131
132
133
134
135
136
137
138
141
142
145

FIG. 5D

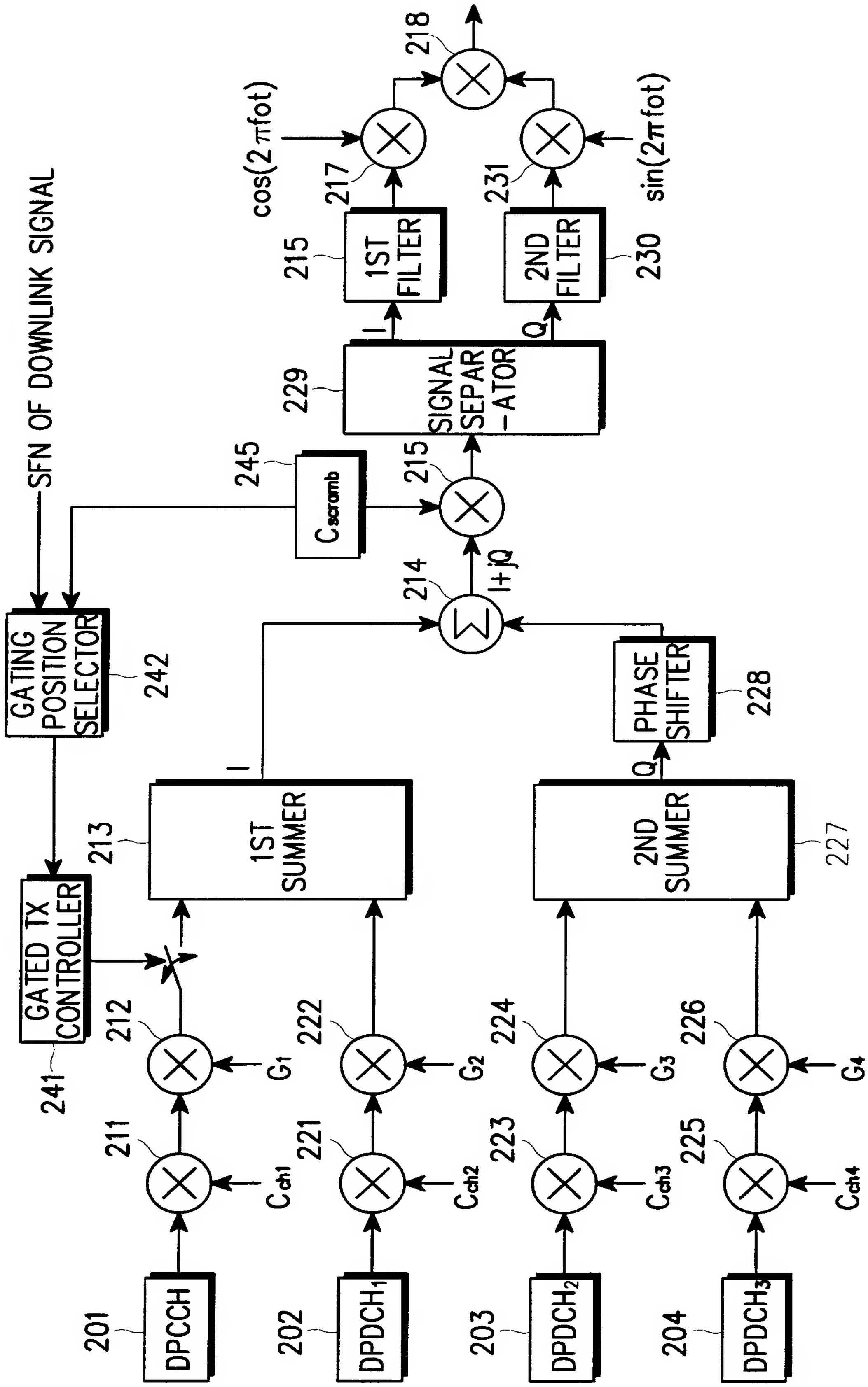

SFN OF DOWNLINK SIGNAL
GATING POSITION SELECTOR
242
GATED TX CONTROLLER
241
245
C_{scramb}
215
229
SIGNAL SEPAR -ATOR
I
Q
1ST FILTER
2ND FILTER
215
230
217
231
cos(2πfot)
sin(2πfot)
218
214
I+jQ
PHASE SHIFTER
228
1ST SUMMER
213
2ND SUMMER
227
201
DPCCH
202
$DPDCH_1$
203
$DPDCH_2$
204
$DPDCH_3$
211
221
223
225
212
222
224
226
C_{ch1}
C_{ch2}
C_{ch3}
C_{ch4}
G_1
G_2
G_3
G_4

FIG. 6A

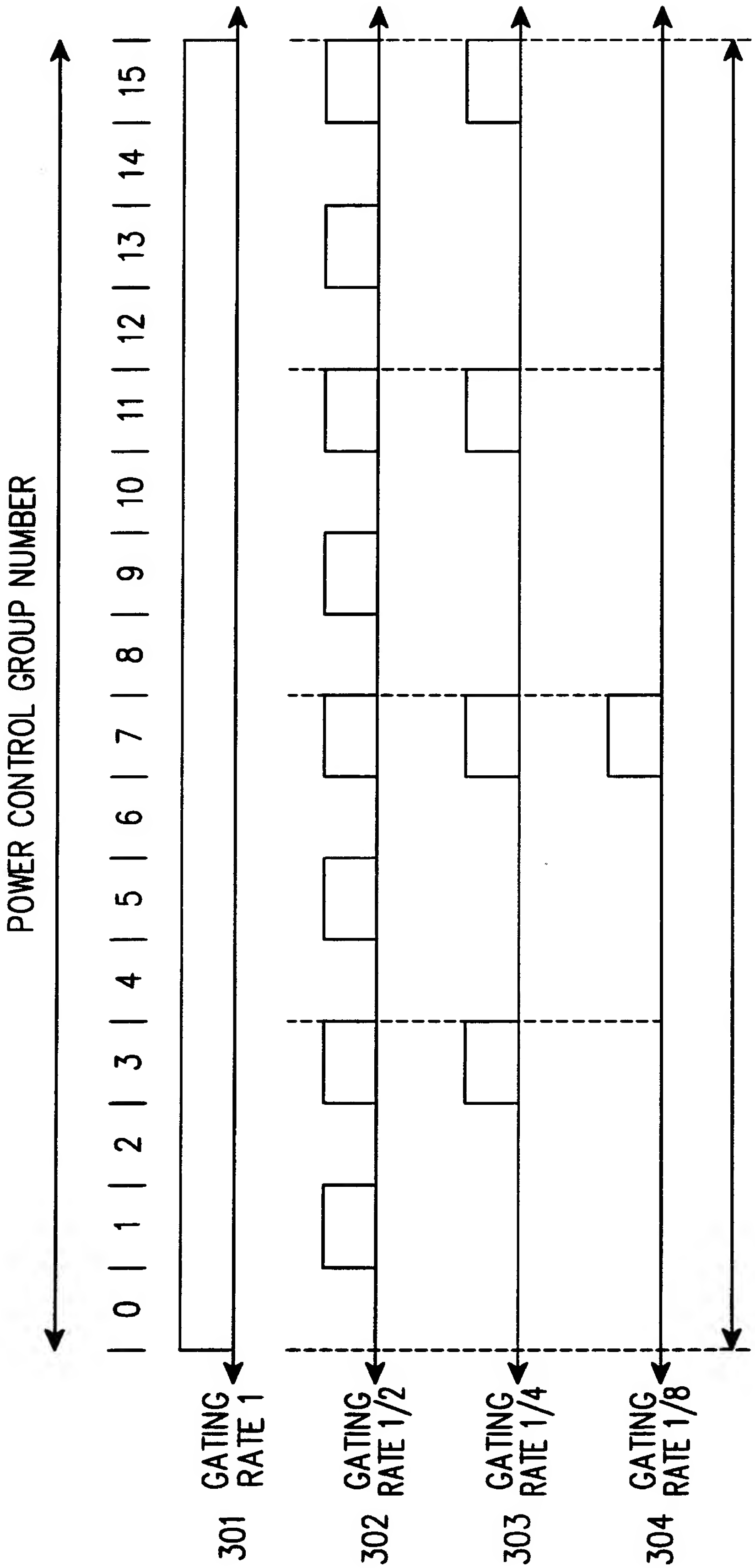

POWER CONTROL GROUP NUMBER
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
301 GATING RATE 1
302 GATING RATE 1/2
303 GATING RATE 1/4
304 GATING RATE 1/8

FIG. 6B

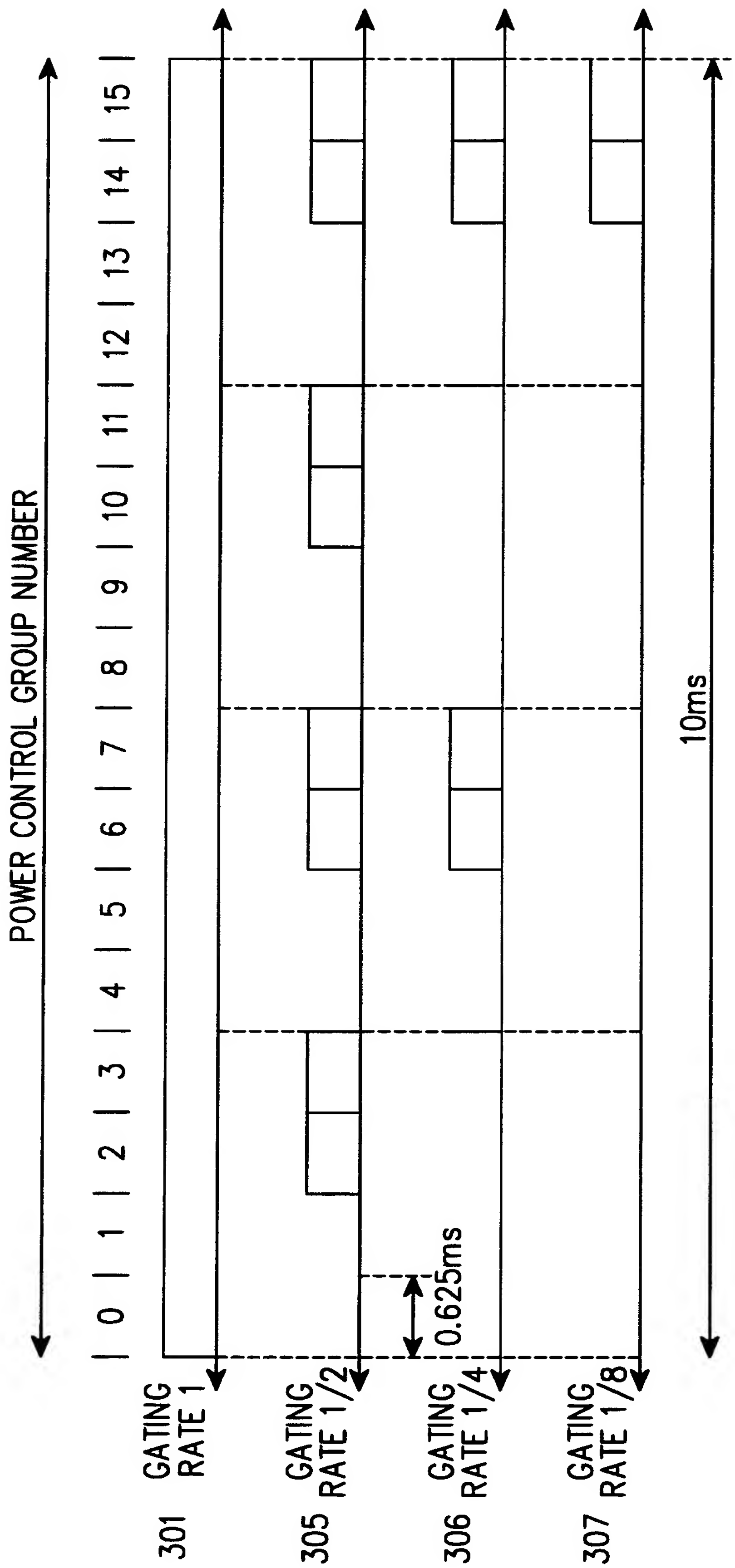

POWER CONTROL GROUP NUMBER
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.625ms
10ms
301
GATING RATE 1
305
GATING RATE 1/2
306
GATING RATE 1/4
307
GATING RATE 1/8

FIG. 7A

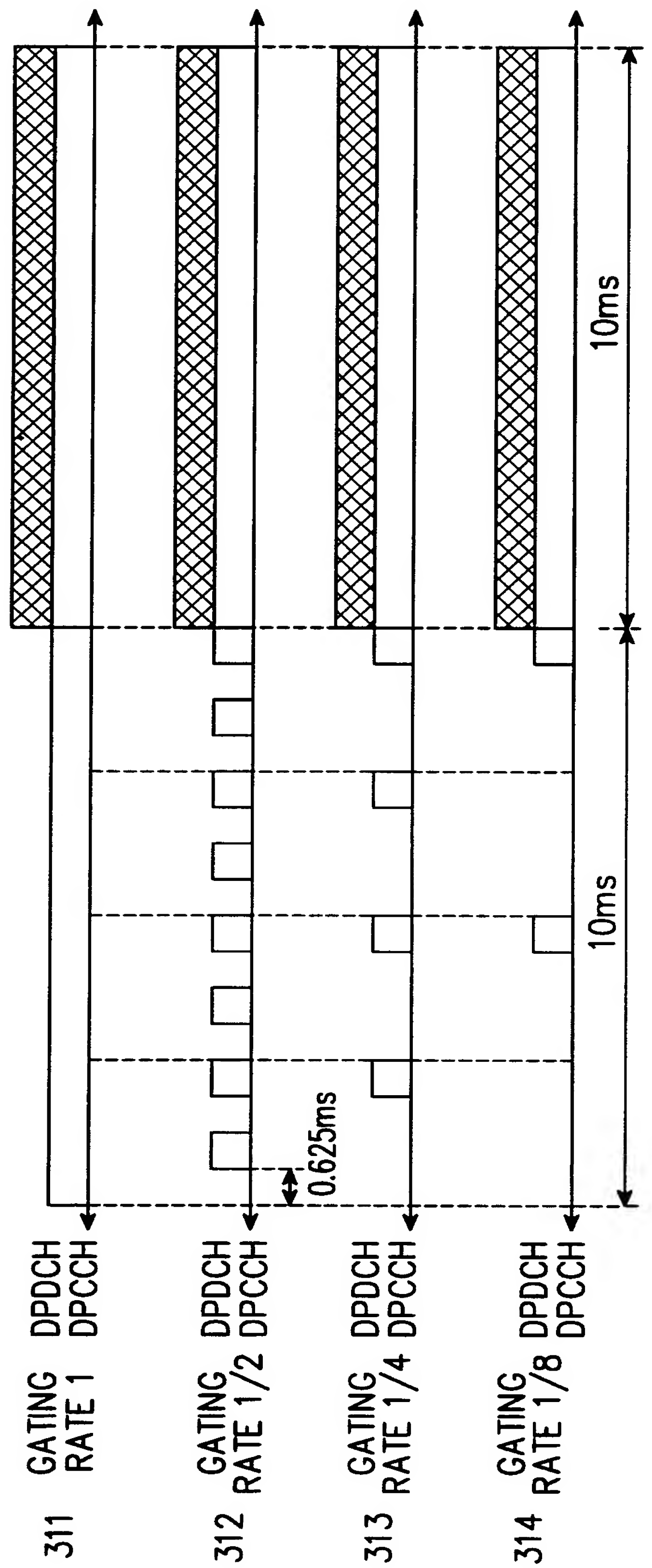

311 GATING RATE 1
DPDCH
DPCCH
312 GATING RATE 1/2
DPDCH
DPCCH
313 GATING RATE 1/4
DPDCH
DPCCH
314 GATING RATE 1/8
DPDCH
DPCCH
0.625ms
10ms
10ms

FIG. 7B

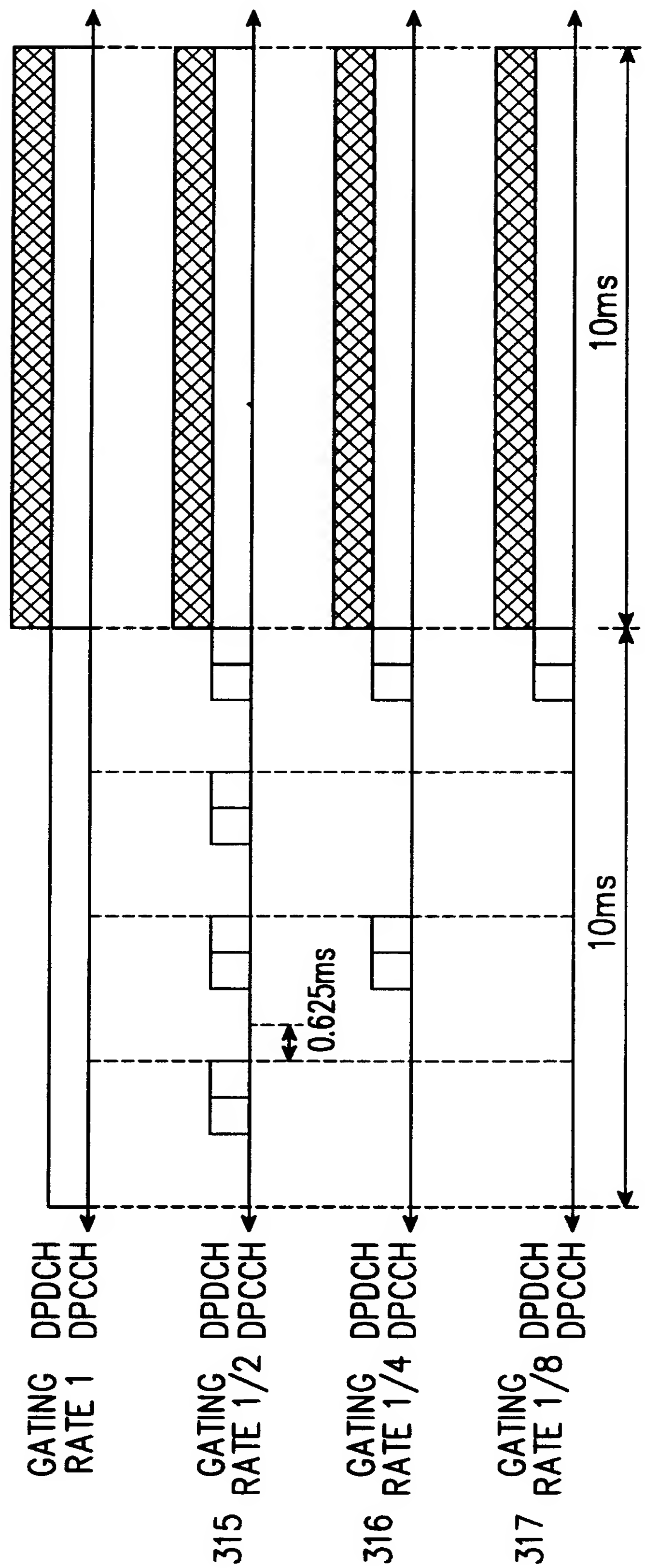
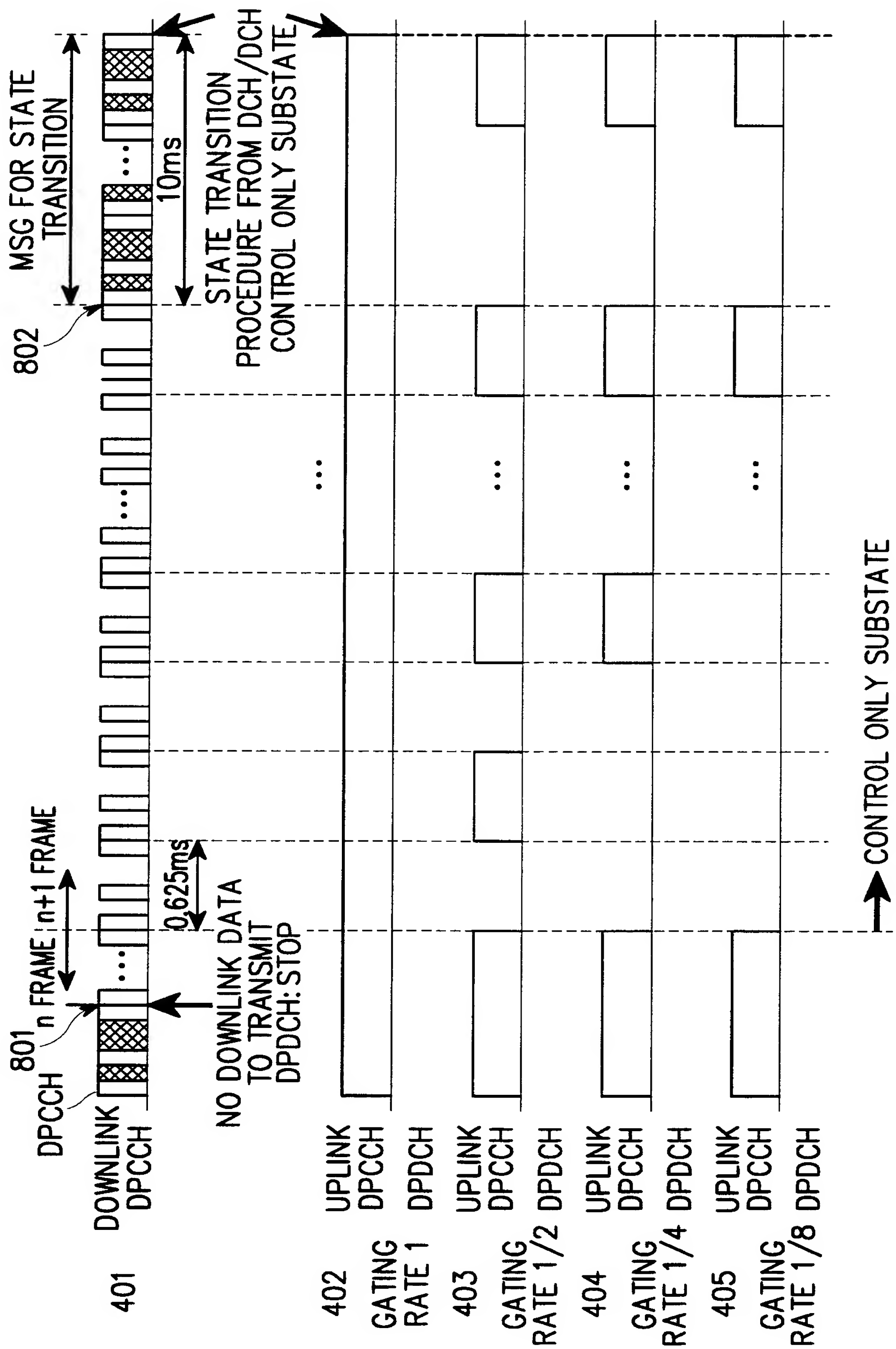

GATING RATE 1
DPDCH
DPCCH
315
GATING RATE 1/2
DPDCH
DPCCH
316
GATING RATE 1/4
DPDCH
DPCCH
317
GATING RATE 1/8
DPDCH
DPCCH
0.625ms
10ms
10ms

FIG. 8A



401
DOWNLINK DPCCH
DPCCH
801
n FRAME
n+1 FRAME
0.625ms
NO DOWNLINK DATA TO TRANSMIT DPDCH:STOP
802
MSG FOR STATE TRANSITION
10ms
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
402
GATING RATE 1
UPLINK DPCCH
DPDCH
403
GATING RATE 1/2
UPLINK DPCCH
DPDCH
404
GATING RATE 1/4
UPLINK DPCCH
DPDCH
405
GATING RATE 1/8
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE

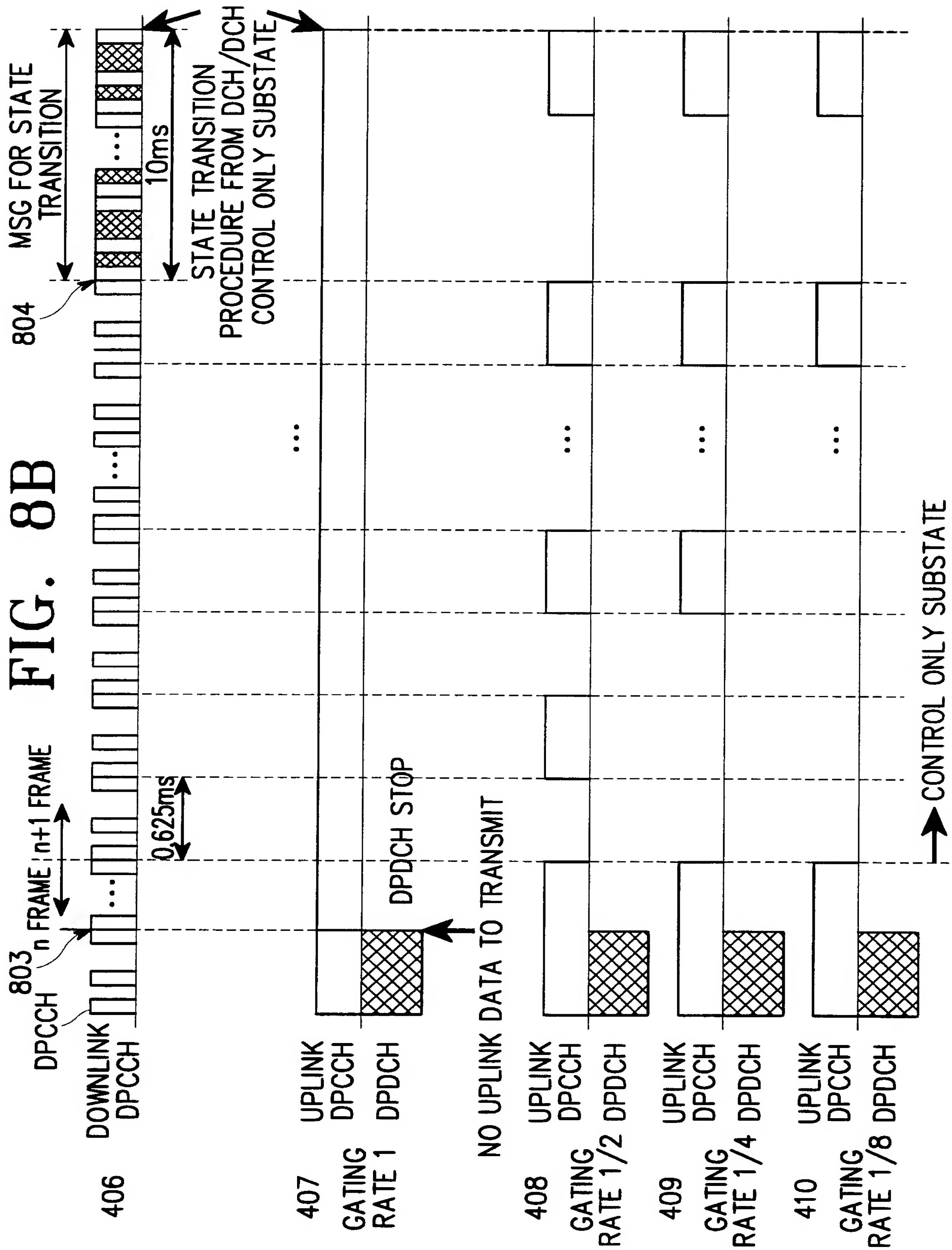


FIG. 8B
406
DOWNLINK DPCCH
DPCCH
803
n FRAME
n+1 FRAME
0.625ms
804
MSG FOR STATE TRANSITION
10ms
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
407
GATING RATE 1
UPLINK DPCCH
DPDCH
DPDCH STOP
NO UPLINK DATA TO TRANSMIT
408
GATING RATE 1/2
UPLINK DPCCH
DPDCH
409
GATING RATE 1/4
UPLINK DPCCH
DPDCH
410
GATING RATE 1/8
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE

FIG. 8C

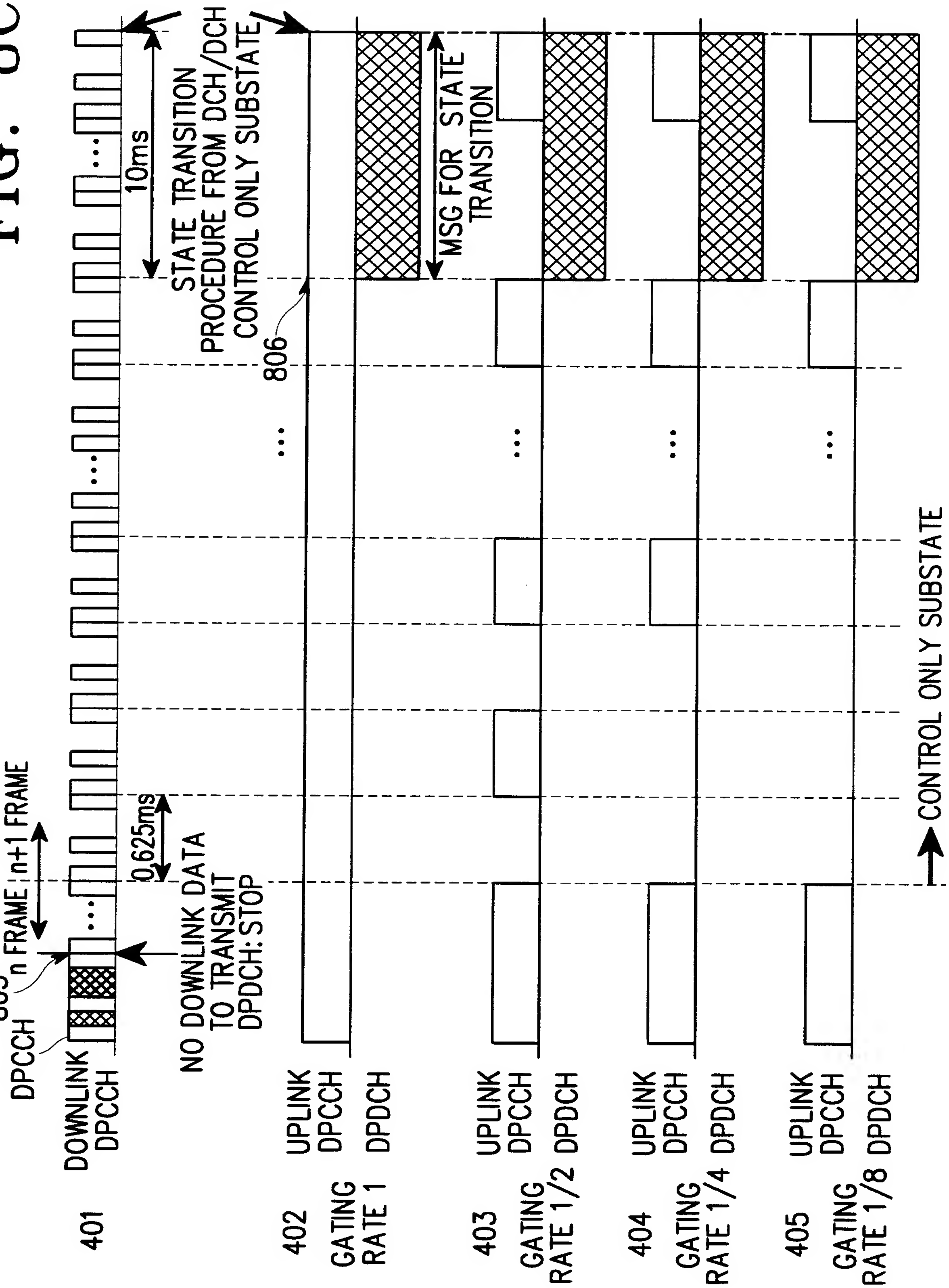

401
DOWNLINK DPCCH
DPCCH
805
n FRAME
n+1 FRAME
0.625ms
10ms
NO DOWNLINK DATA TO TRANSMIT DPDCH: STOP
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
806
MSG FOR STATE TRANSITION
402
GATING RATE 1
UPLINK DPCCH
DPDCH
403
GATING RATE 1/2
UPLINK DPCCH
DPDCH
404
GATING RATE 1/4
UPLINK DPCCH
DPDCH
405
GATING RATE 1/8
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE

FIG. 8D

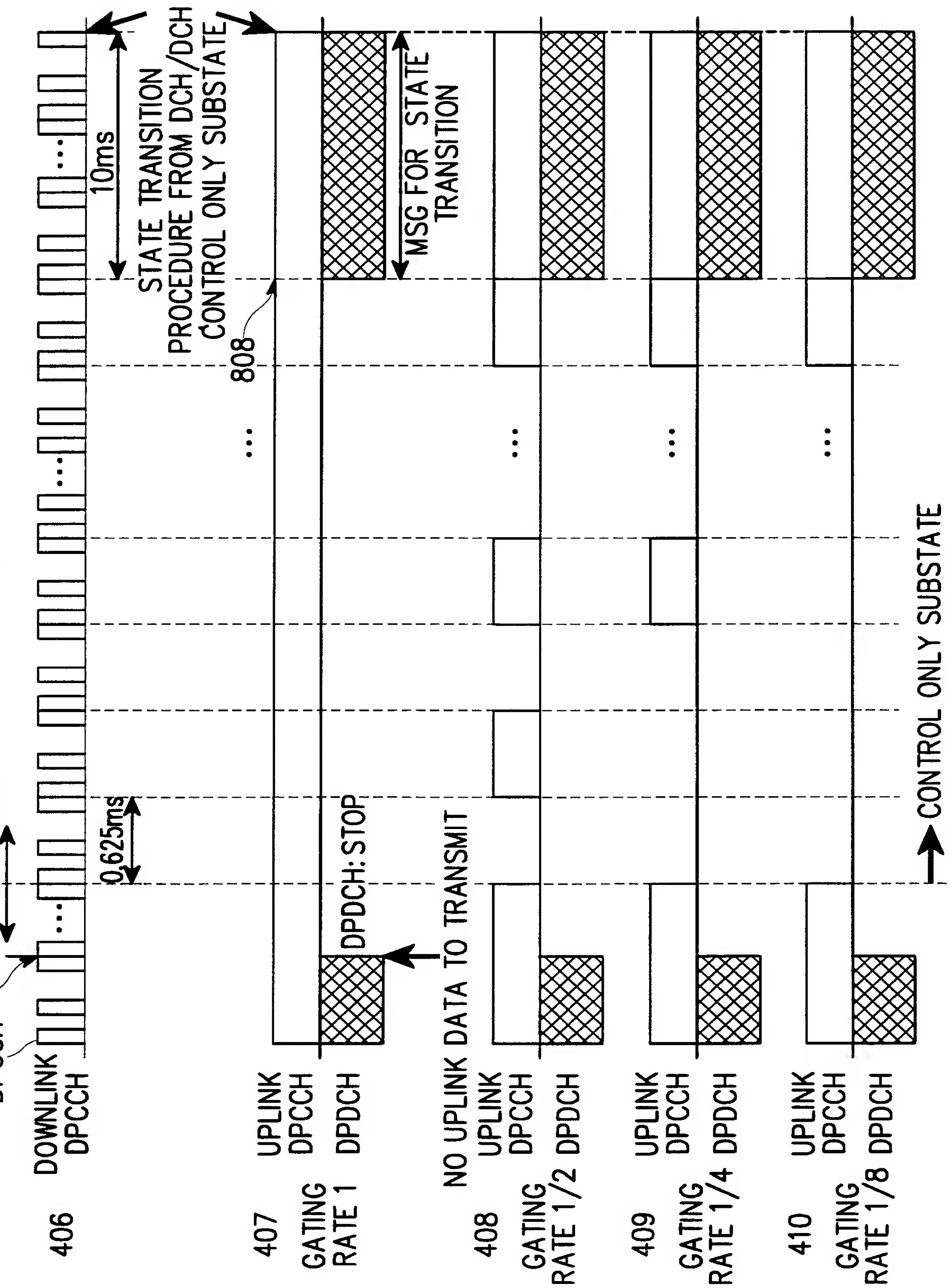

406
DOWNLINK DPCCH
DPCCH
807
n FRAME
n+1 FRAME
0.625ms
10ms
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
808
407
GATING RATE 1
UPLINK DPCCH
DPDCH
DPDCH: STOP
NO UPLINK DATA TO TRANSMIT
MSG FOR STATE TRANSITION
408
GATING RATE 1/2
UPLINK DPCCH
DPDCH
409
GATING RATE 1/4
UPLINK DPCCH
DPDCH
410
GATING RATE 1/8
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE

FIG. 9A

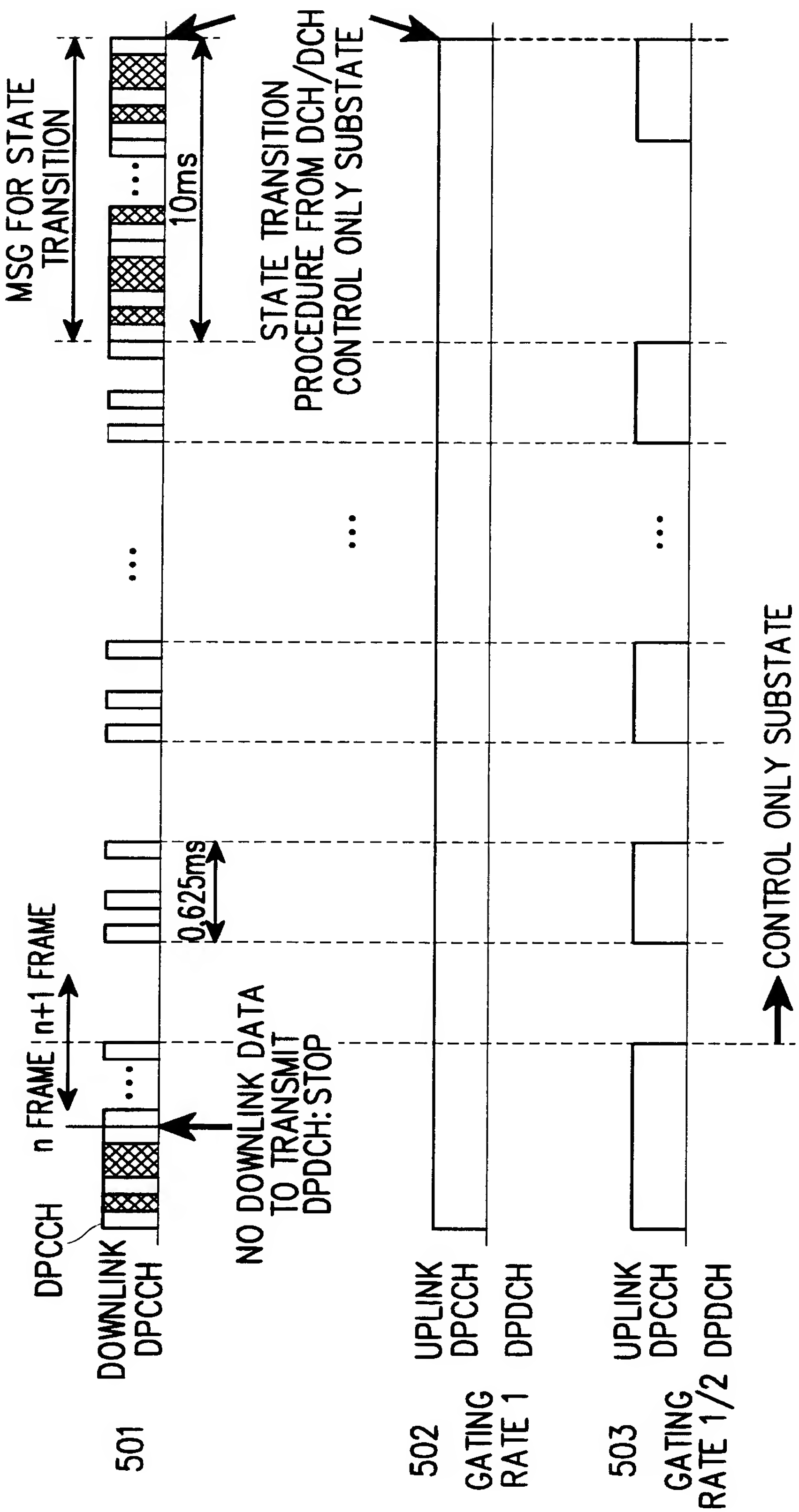
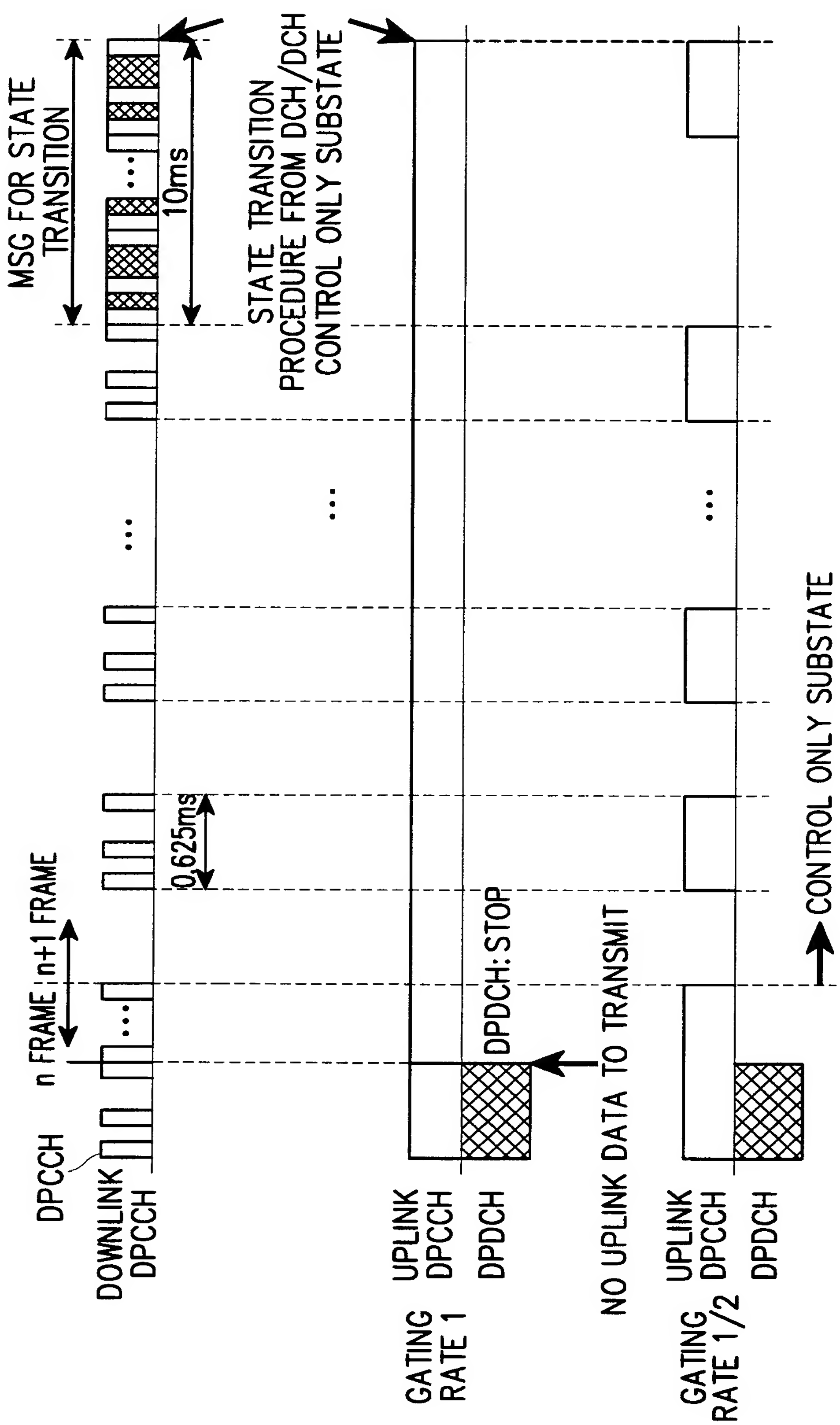
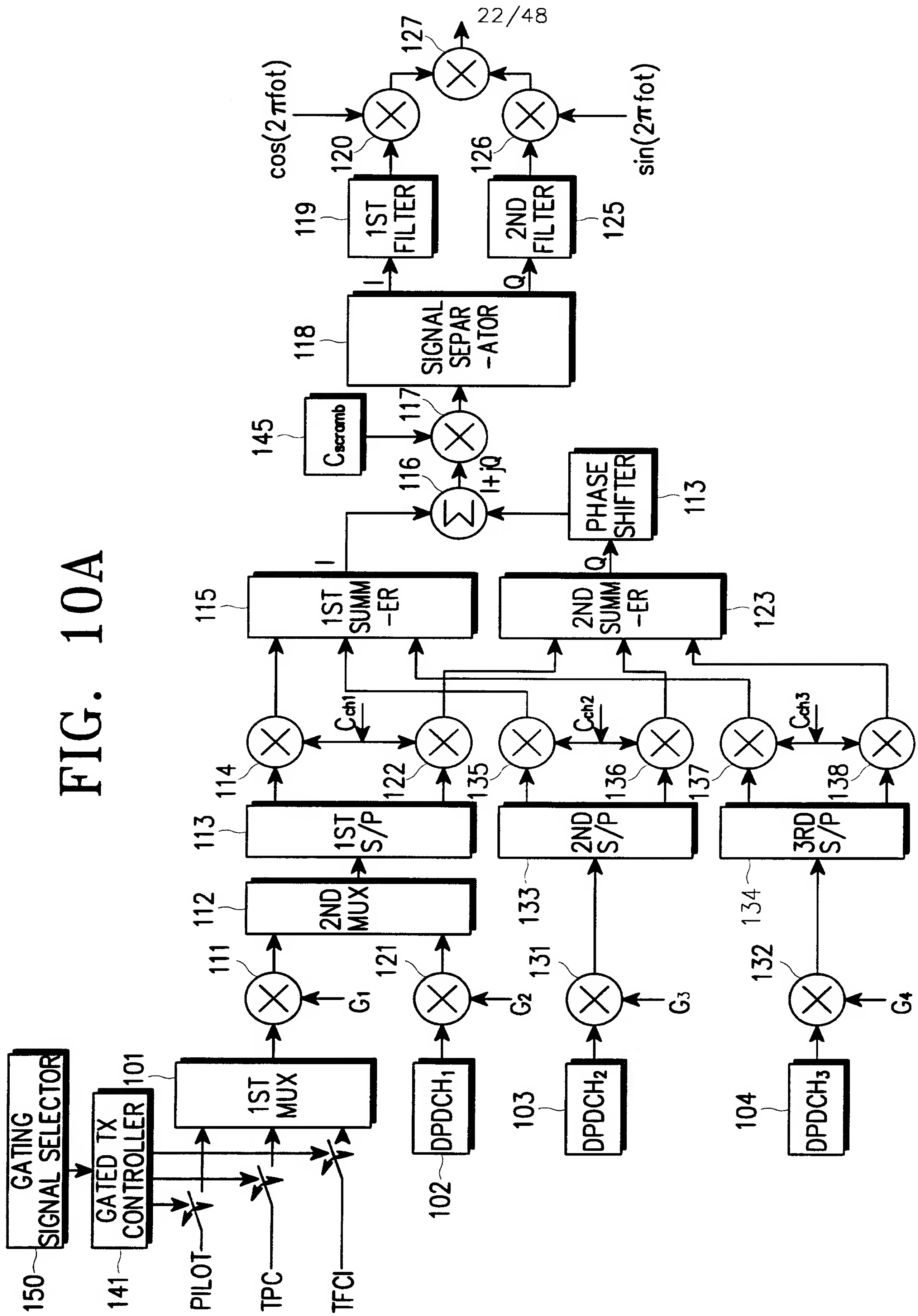

501
DOWNLINK DPCCH
DPCCH
n FRAME
n+1 FRAME
NO DOWNLINK DATA TO TRANSMIT DPDCH:STOP
0.625ms
MSG FOR STATE TRANSITION
10ms
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
502
GATING RATE 1
UPLINK DPCCH
DPDCH
503
GATING RATE 1/2
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE

FIG. 9B

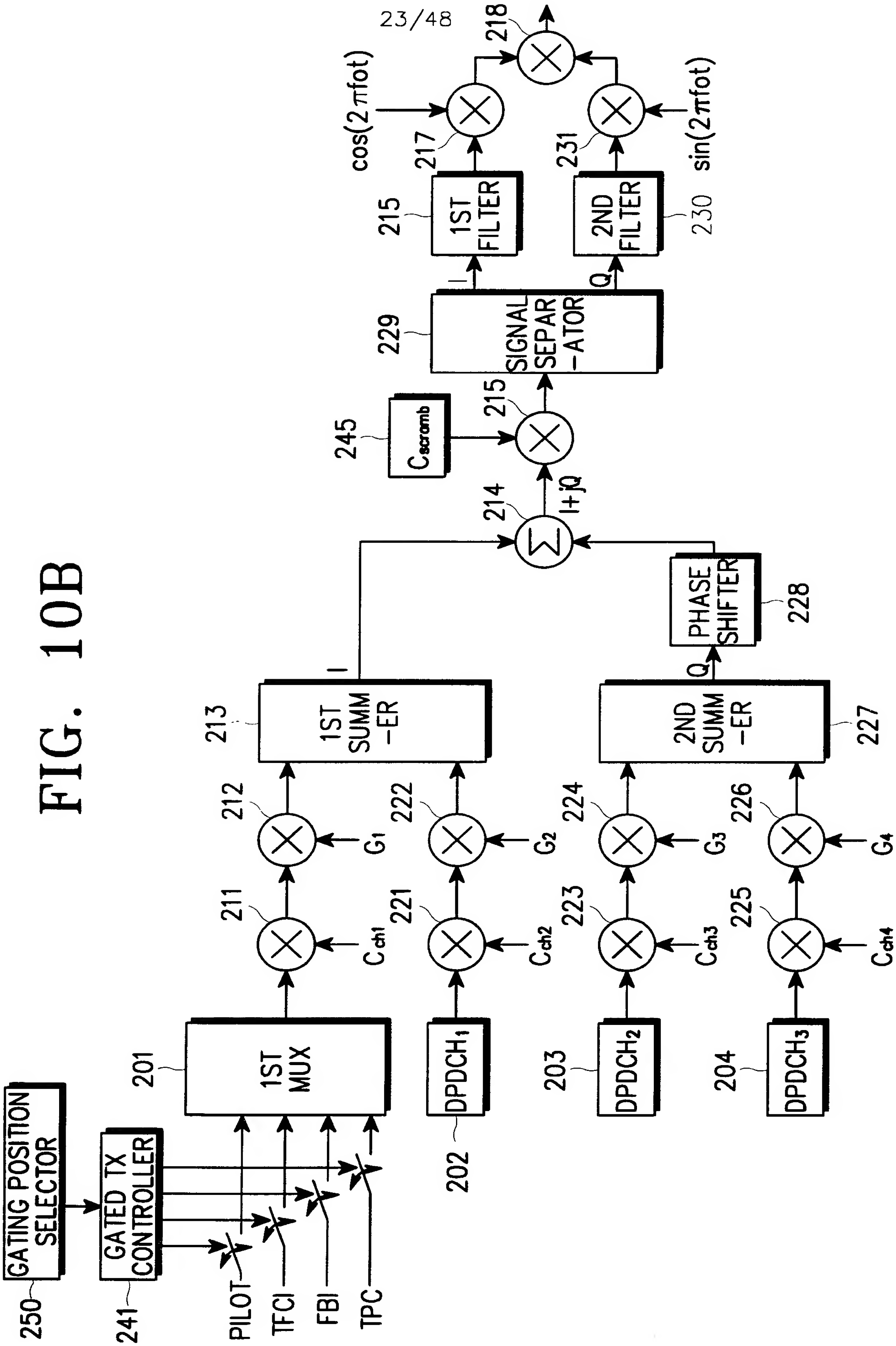

MSG FOR STATE TRANSITION
10ms
STATE TRANSITION PROCEDURE FROM DCH/DCH CONTROL ONLY SUBSTATE
n FRAME
n+1 FRAME
0.625ms
DPCCH
DOWNLINK DPCCH
GATING RATE 1
UPLINK DPCCH
DPDCH
DPDCH:STOP
NO UPLINK DATA TO TRANSMIT
GATING RATE 1/2
UPLINK DPCCH
DPDCH
CONTROL ONLY SUBSTATE



GATING SIGNAL SELECTOR
150
GATED TX CONTROLLER
141
PILOT
TPC
TFCI
1ST MUX
101
DPDCH1
102
DPDCH2
103
DPDCH3
104
G1
G2
G3
G4
111
121
131
132
2ND MUX
112
1ST S/P
113
2ND S/P
133
3RD S/P
134
114
122
135
136
137
138
Cch1
Cch2
Cch3
1ST SUMM -ER
115
2ND SUMM -ER
123
I
Q
PHASE SHIFTER
113
116
I+jQ
Cscramb
145
117
SIGNAL SEPAR -ATOR
118
I
Q
1ST FILTER
119
2ND FILTER
125
120
126
cos(2πfot)
sin(2πfot)
127

FIG. 10A

FIG. 10B


GATING POSITION SELECTOR
250
GATED TX CONTROLLER
241
PILOT
TFCI
FBI
TPC
1ST MUX
201
DPDCH1
202
DPDCH2
203
DPDCH3
204
Cch1
Cch2
Cch3
Cch4
211
221
223
225
G1
G2
G3
G4
212
222
224
226
1ST SUMM -ER
213
2ND SUMM -ER
227
I
Q
PHASE SHIFTER
228
214
I+jQ
Cscramb
245
215
SIGNAL SEPAR -ATOR
229
1ST FILTER
215
2ND FILTER
230
217
231
cos(2πfot)
sin(2πfot)
218

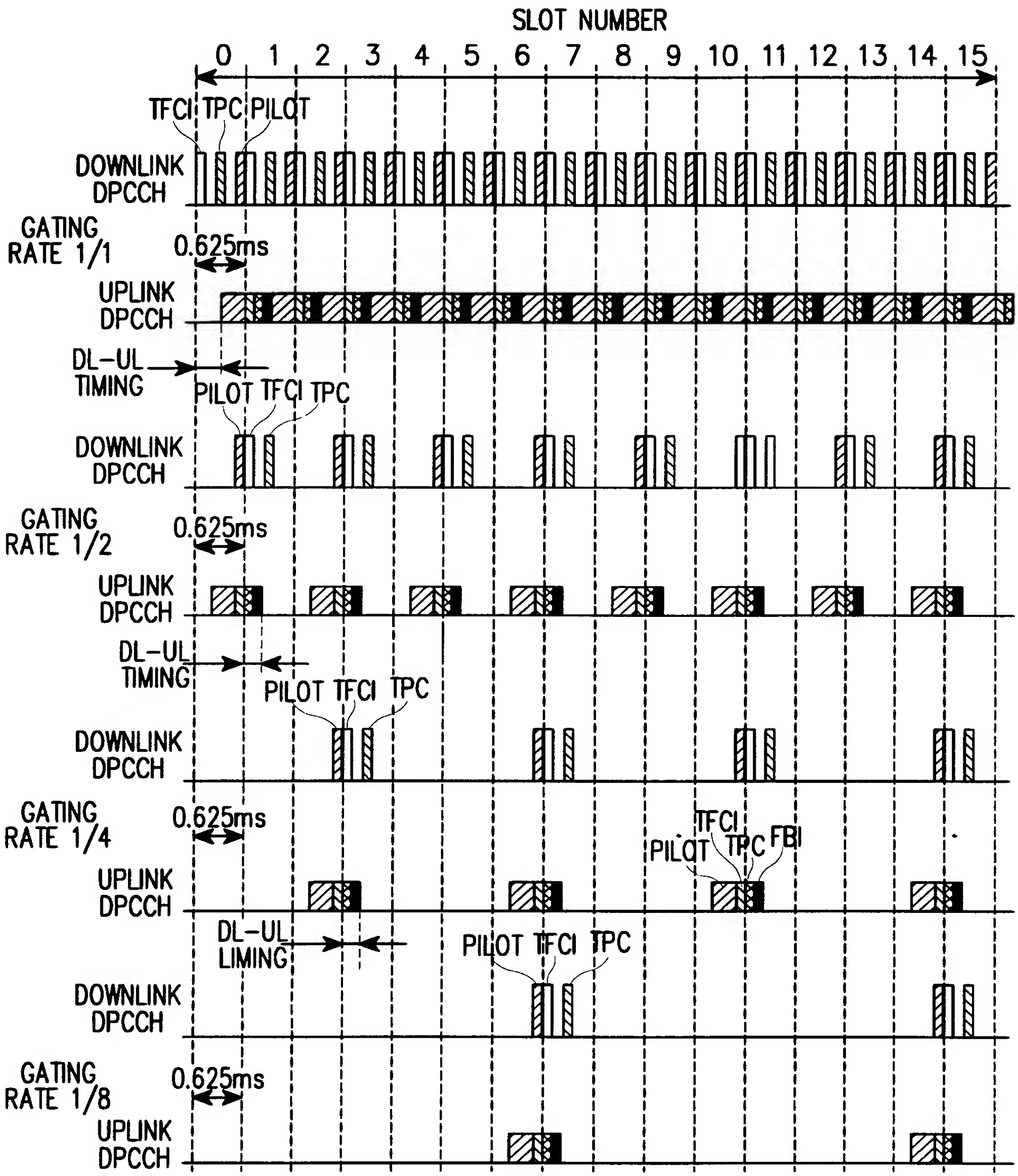

SLOT NUMBER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TFCI TPC PILOT
DOWNLINK DPCCH
GATING RATE 1/1
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/2
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/4
0.625ms
TFCI
PILOT TPC FBI
UPLINK DPCCH
DL-UL LIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/8
0.625ms
UPLINK DPCCH

FIG. 11A

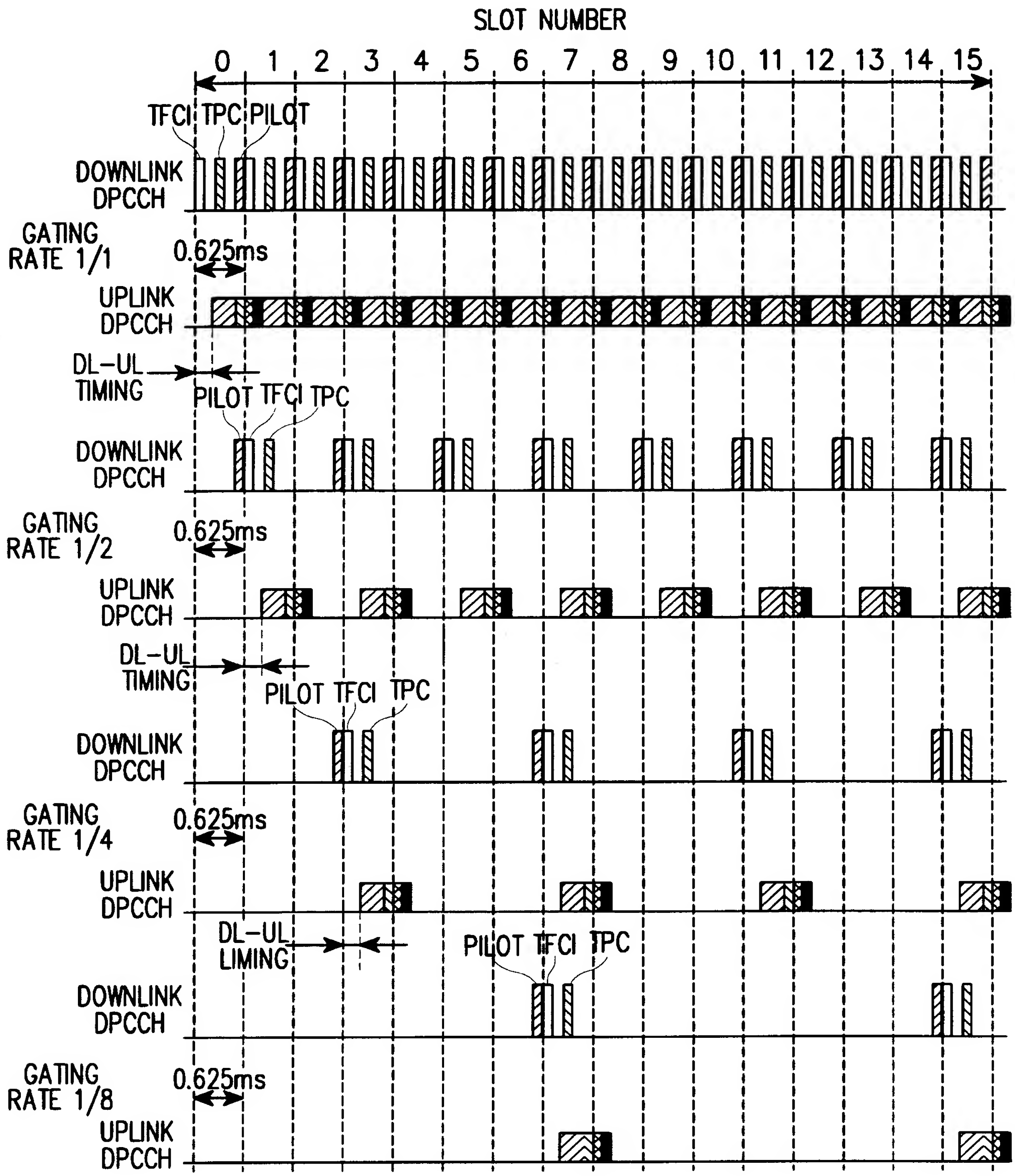

SLOT NUMBER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TFCI TPC PILOT
DOWNLINK DPCCH
GATING RATE 1/1
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/2
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/4
0.625ms
UPLINK DPCCH
DL-UL LIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/8
0.625ms
UPLINK DPCCH

FIG. 11B

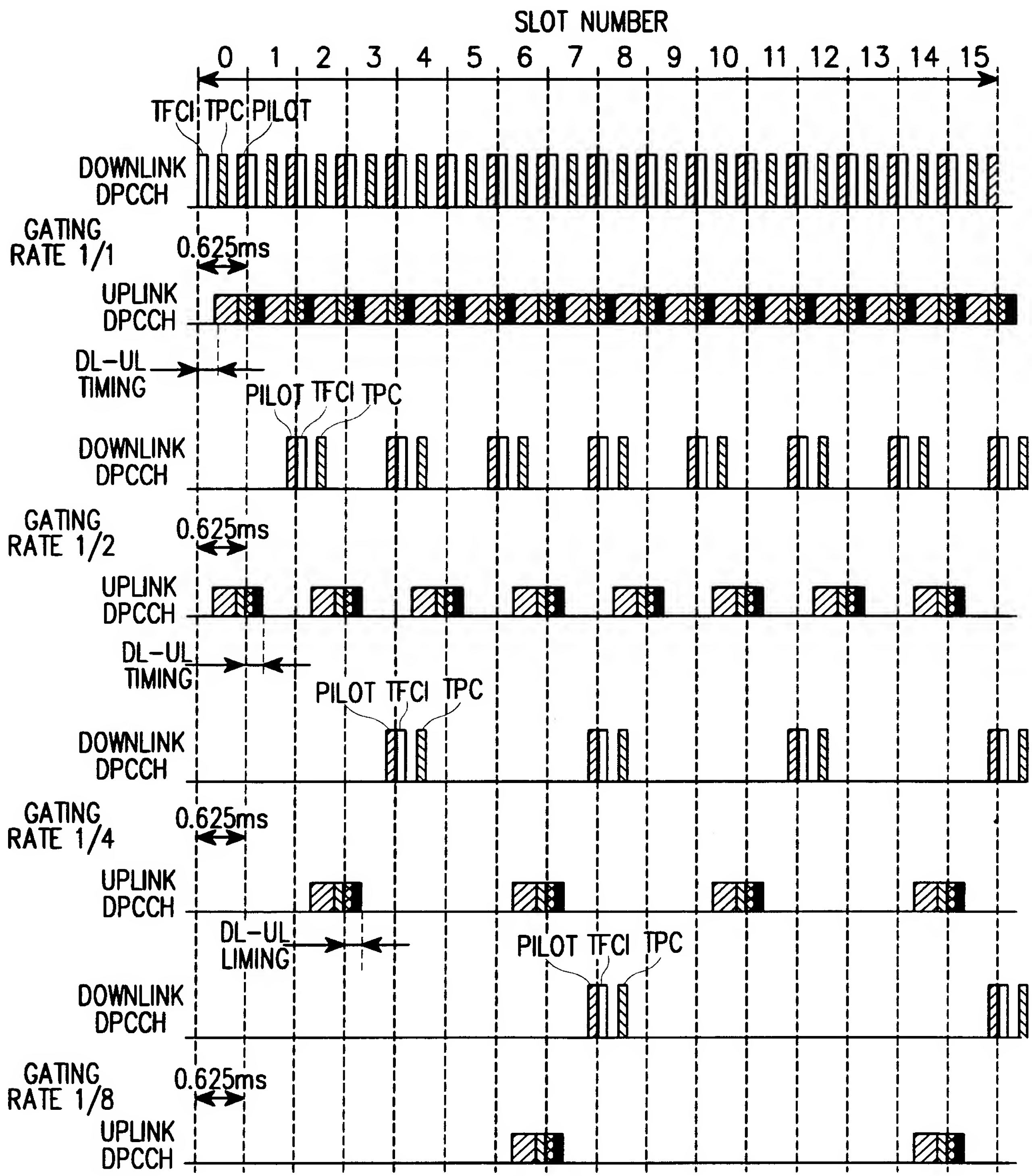

SLOT NUMBER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TFCI TPC PILOT
DOWNLINK DPCCH
GATING RATE 1/1
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/2
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/4
0.625ms
UPLINK DPCCH
DL-UL LIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/8
0.625ms
UPLINK DPCCH

FIG. 11C

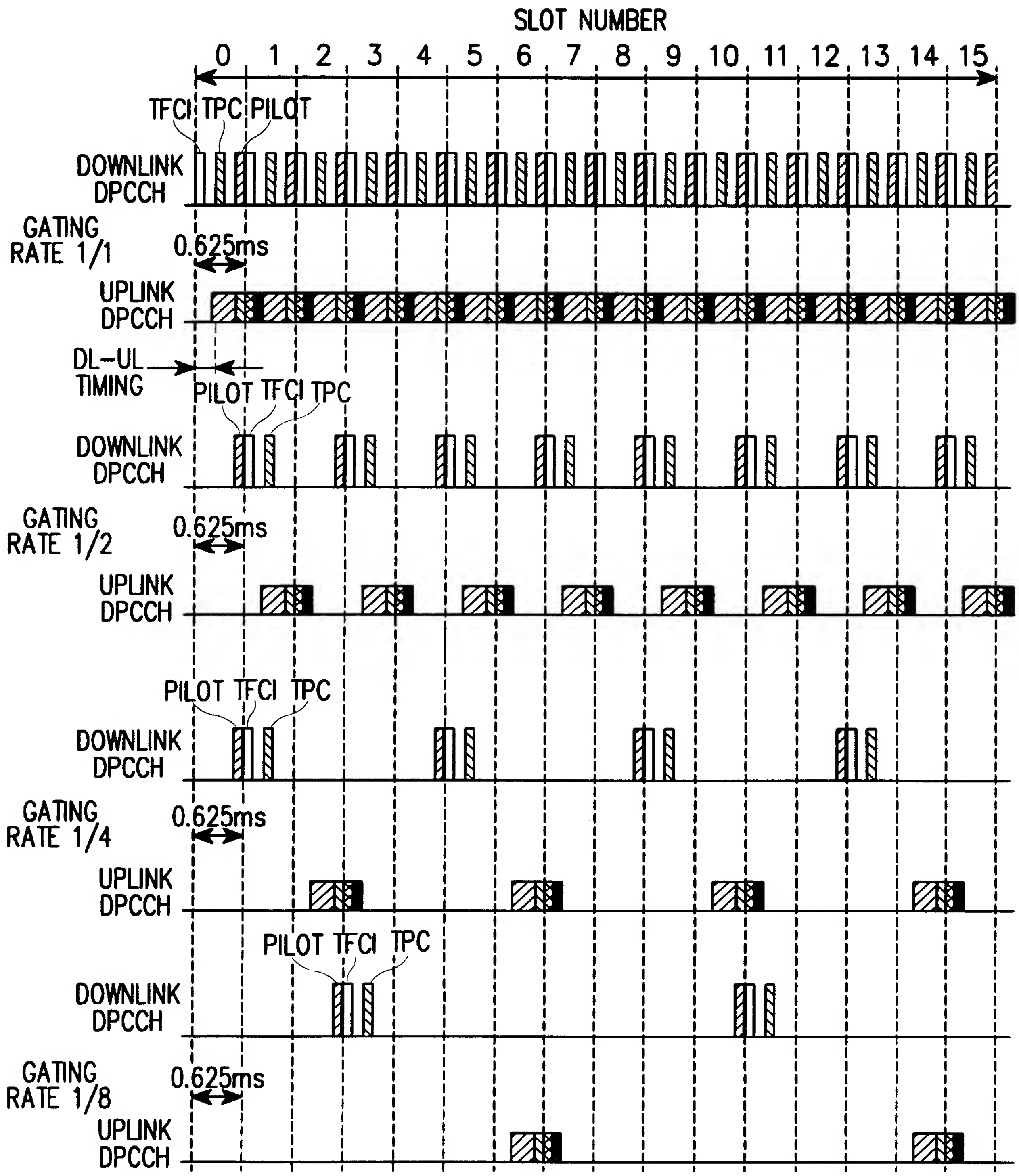

SLOT NUMBER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TFCI TPC PILOT
DOWNLINK DPCCH
GATING RATE 1/1
0.625ms
UPLINK DPCCH
DL-UL TIMING
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/2
0.625ms
UPLINK DPCCH
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/4
0.625ms
UPLINK DPCCH
PILOT TFCI TPC
DOWNLINK DPCCH
GATING RATE 1/8
0.625ms
UPLINK DPCCH

FIG. 11D

FIG. 12A

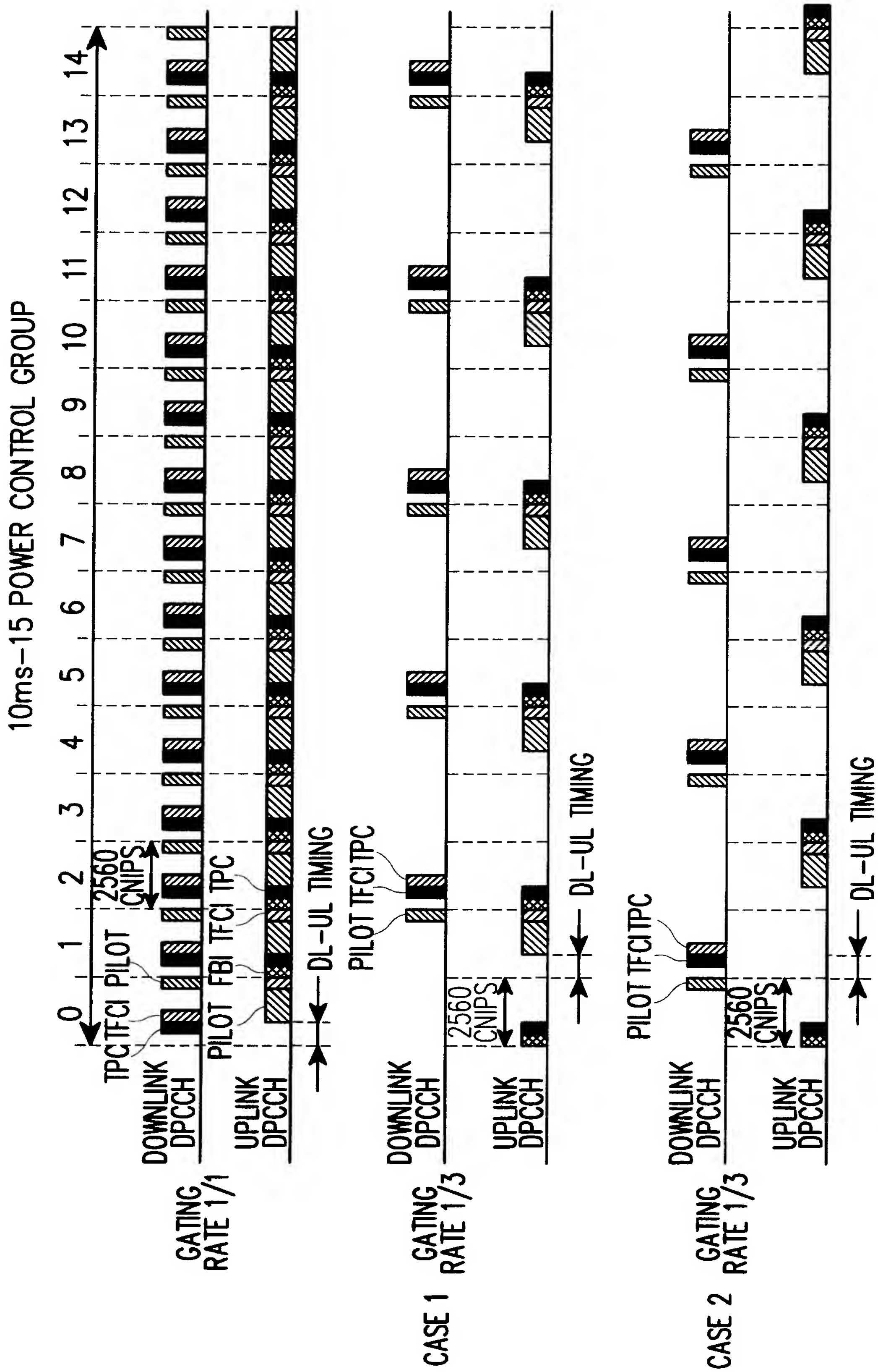

10ms-15 POWER CONTROL GROUP
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
2560 CNIPS
TPC TFCI PILOT
PILOT FBI TFCI TPC
DL-UL TIMING
PILOT TFCI TPC
GATING RATE 1/1
DOWNLINK DPCCH
UPLINK DPCCH
CASE 1
GATING RATE 1/3
CASE 2

FIG. 12B

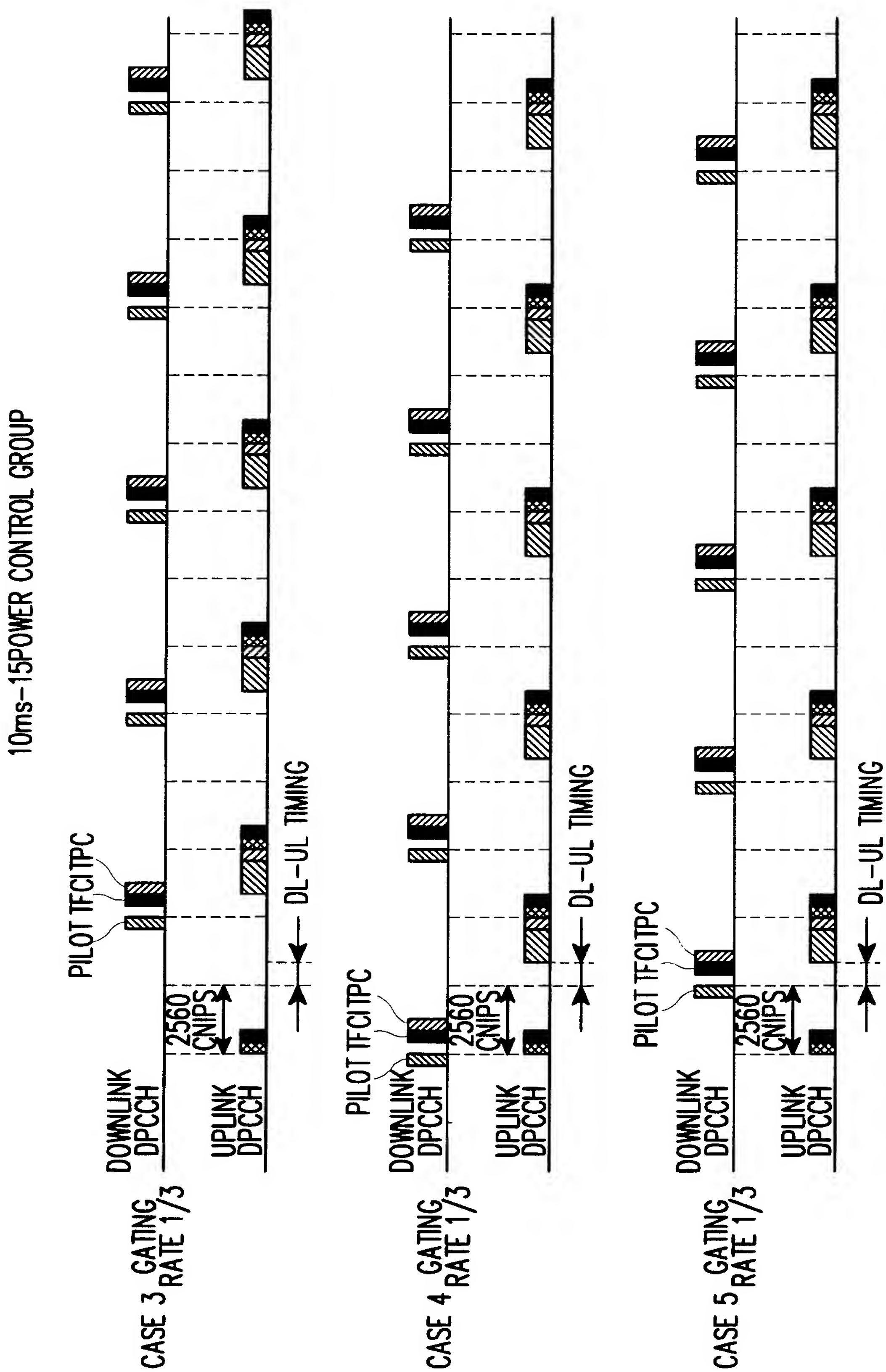

10ms-15POWER CONTROL GROUP
CASE 3 GATING RATE 1/3
DOWNLINK DPCCH
UPLINK DPCCH
PILOT TFCITPC
2560 CNIPS
DL-UL TIMING
CASE 4 GATING RATE 1/3
DOWNLINK DPCCH
UPLINK DPCCH
PILOT TFCITPC
2560 CNIPS
DL-UL TIMING
CASE 5 GATING RATE 1/3
DOWNLINK DPCCH
UPLINK DPCCH
PILOT TFCITPC
2560 CNIPS
DL-UL TIMING

FIG. 12C

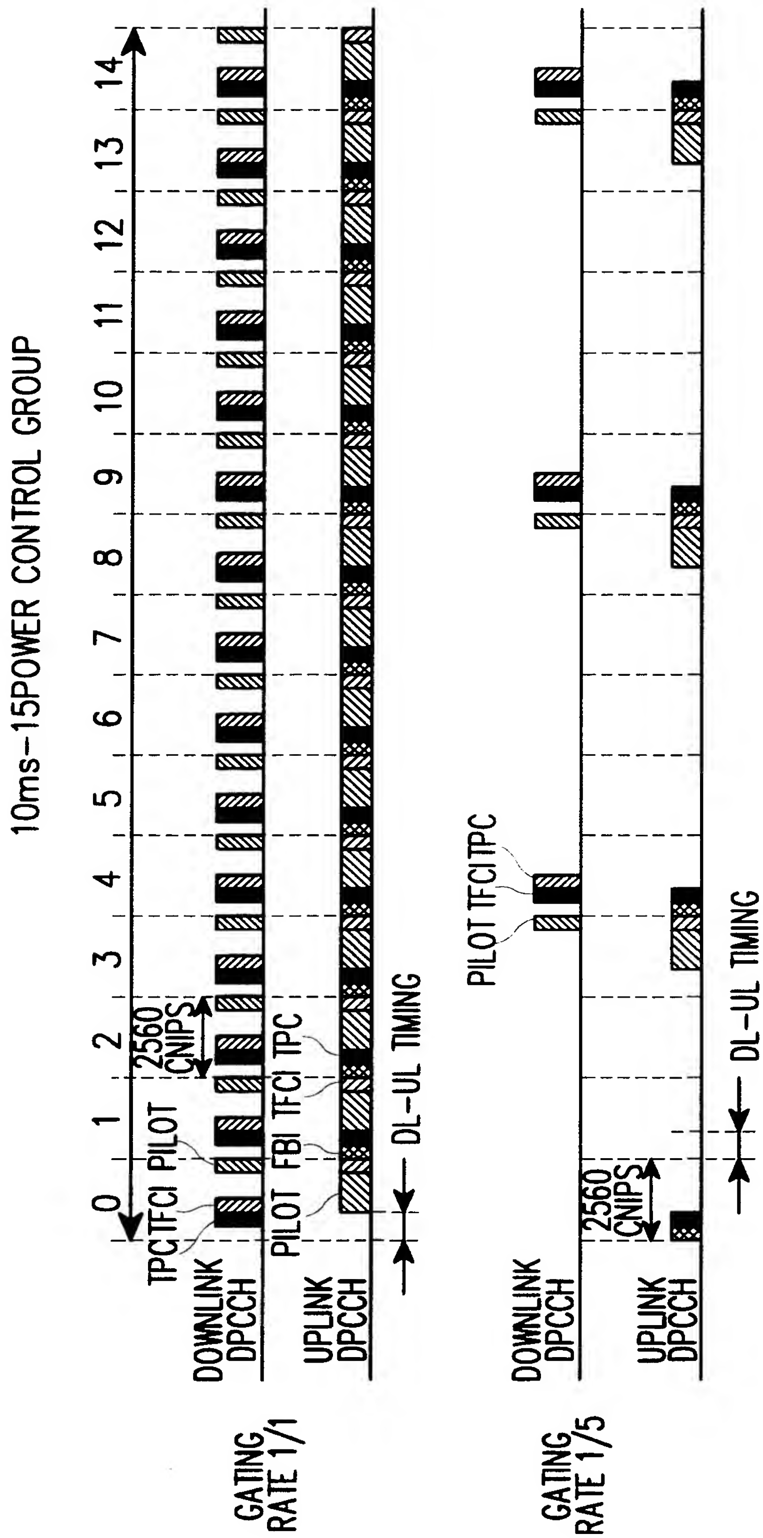

10ms-15POWER CONTROL GROUP
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
GATING RATE 1/1
DOWNLINK DPCCH
TPC TFCI PILOT
2560 CNIPS
UPLINK DPCCH
PILOT FBI TFCI TPC
DL-UL TIMING
GATING RATE 1/5
DOWNLINK DPCCH
PILOT TFCI TPC
UPLINK DPCCH
2560 CNIPS
DL-UL TIMING

FIG. 12D

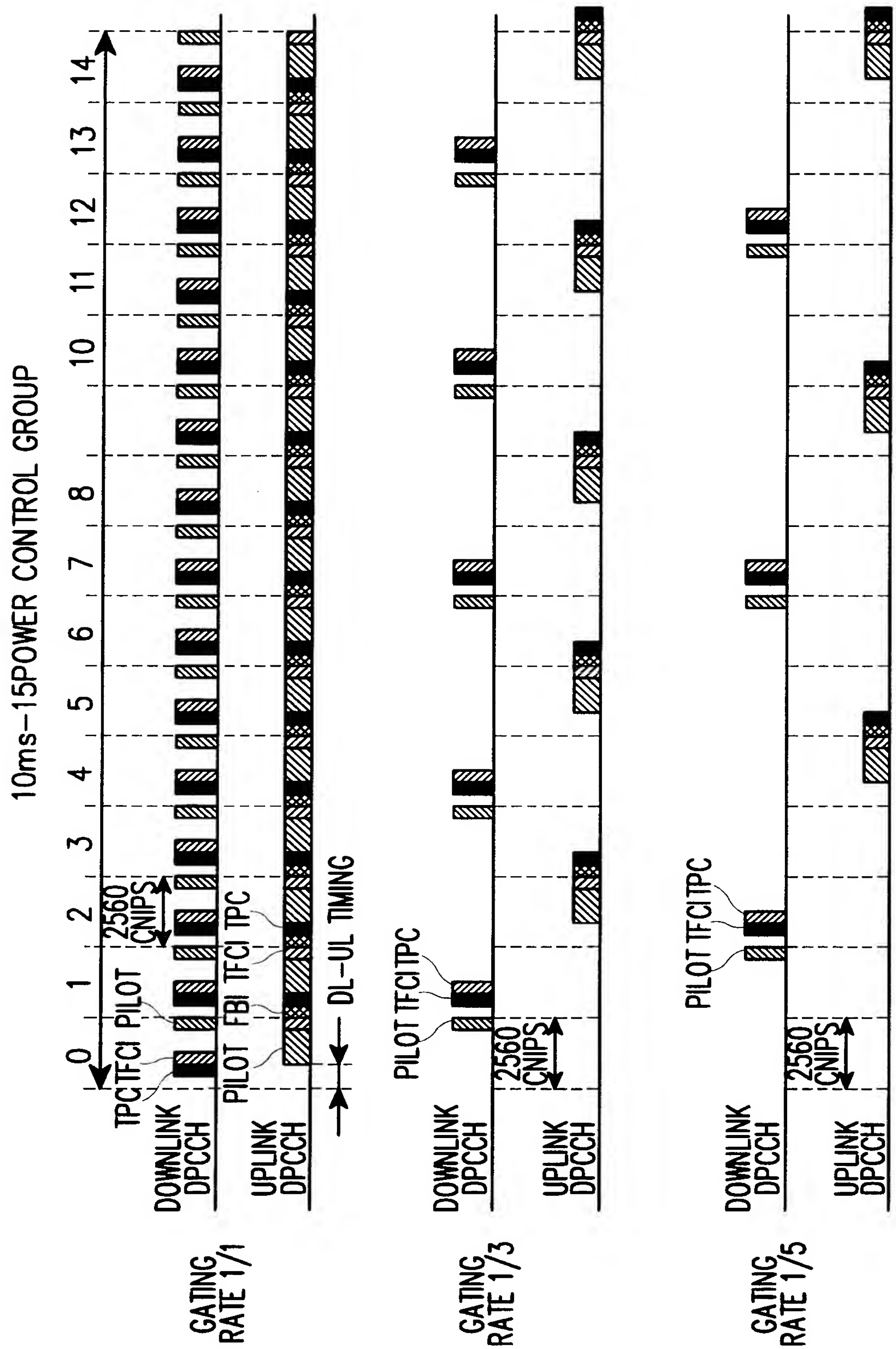

10ms-15POWER CONTROL GROUP
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
TPC TFCI PILOT
2560 CNIPS
PILOT FBI TFCI TPC
DL-UL TIMING
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/1
PILOT TFCI TPC
2560 CNIPS
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/3
PILOT TFCI TPC
2560 CNIPS
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/5

FIG. 12E

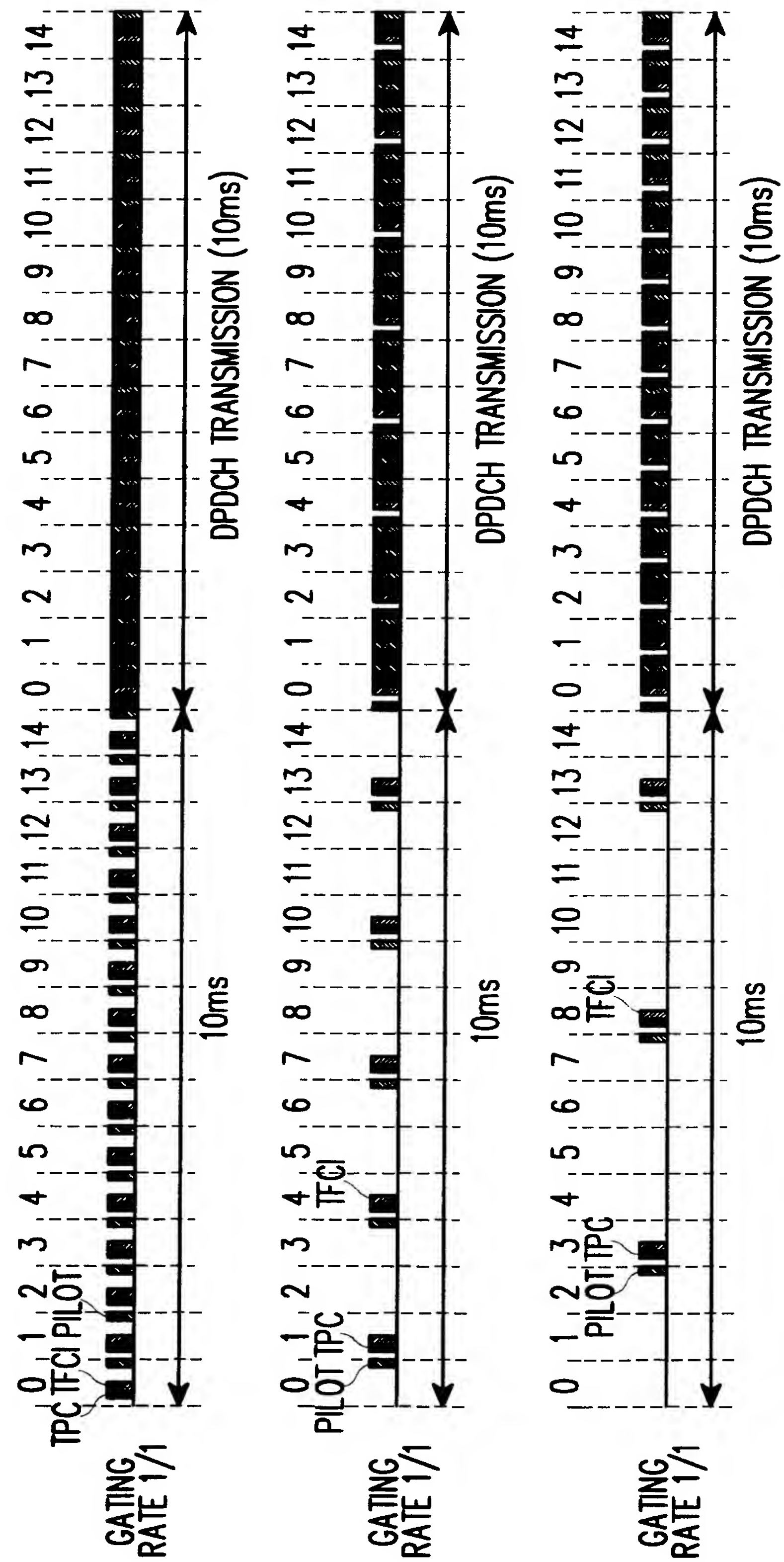

GATING RATE 1/1
TPC TFCI PILOT
PILOT TPC
TFCI
10ms
DPDCH TRANSMISSION (10ms)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

FIG. 13A

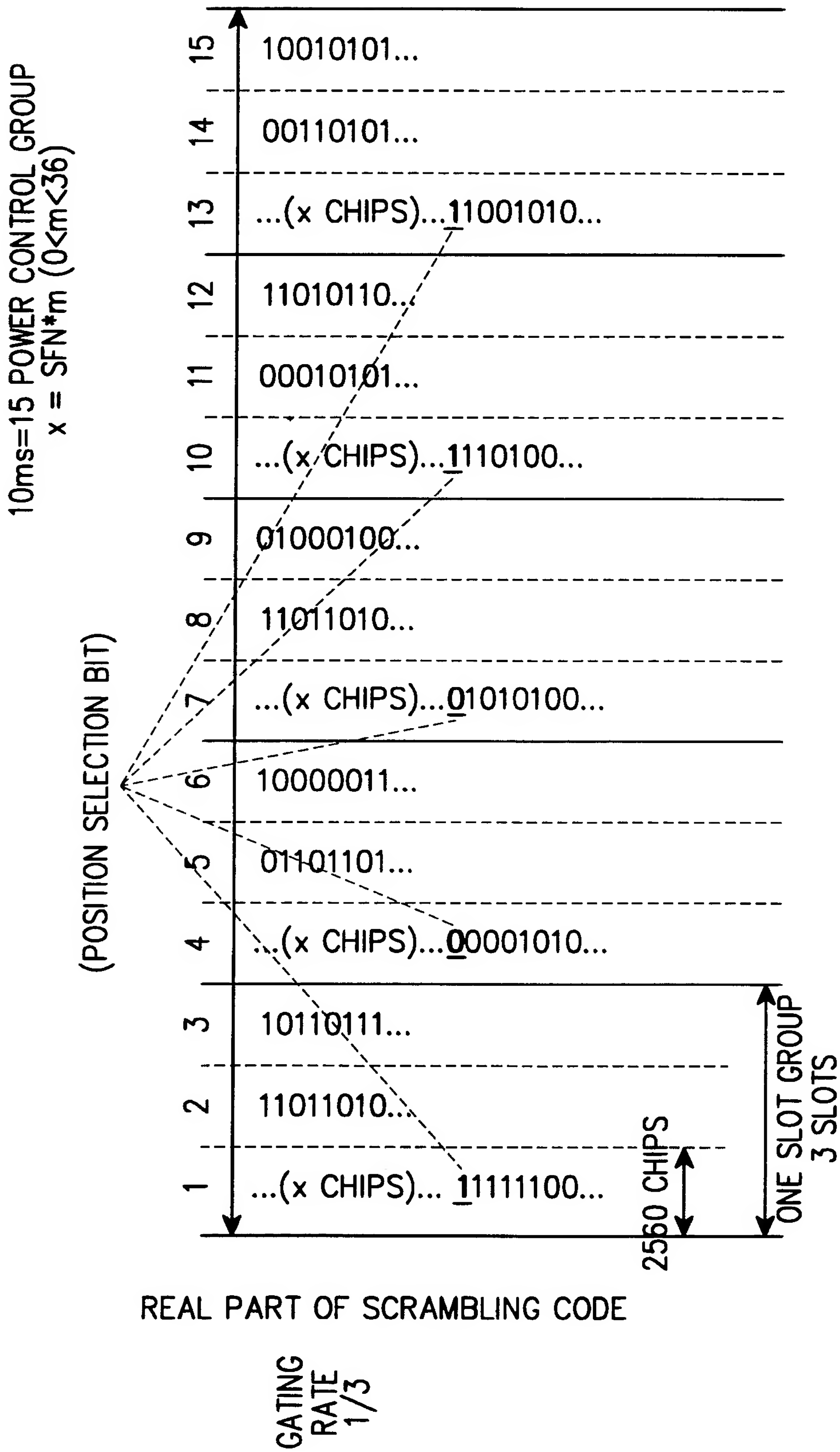

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
(POSITION SELECTION BIT)
15
10010101...
14
00110101...
13
...(x CHIPS)...11001010...
12
11010110...
11
00010101...
10
...(x CHIPS)...1110100...
9
01000100...
8
11011010...
7
...(x CHIPS)...01010100...
6
10000011...
5
01101101...
4
...(x CHIPS)...00001010...
3
10110111...
2
11011010...
1
...(x CHIPS)... 11111100...
2560 CHIPS
ONE SLOT GROUP
3 SLOTS
REAL PART OF SCRAMBLING CODE
GATING
RATE
1/3

FIG. 13B

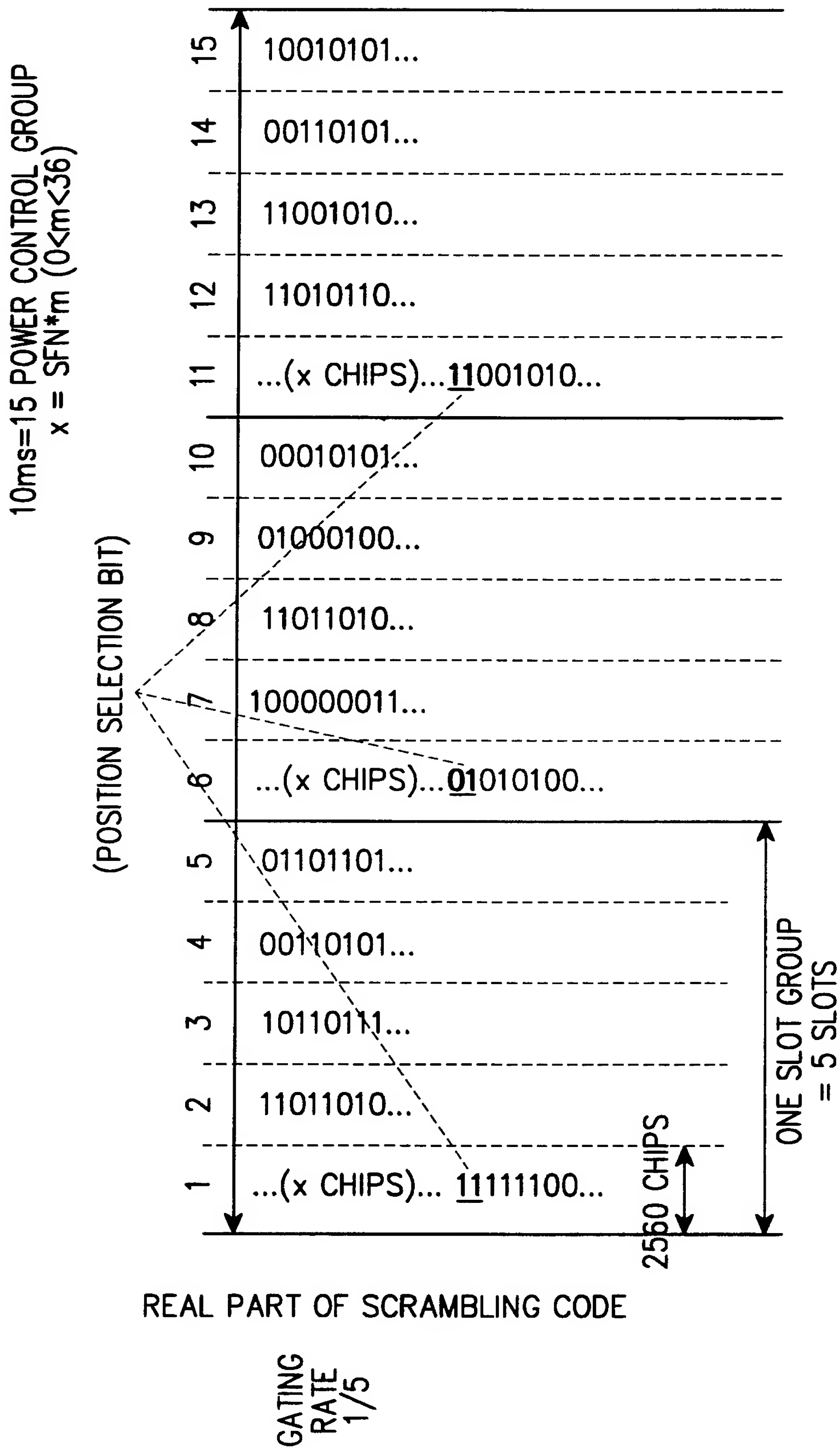

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
(POSITION SELECTION BIT)
15
10010101...
14
00110101...
13
11001010...
12
11010110...
11
...(x CHIPS)...11001010...
10
00010101...
9
01000100...
8
11011010...
7
100000011...
6
...(x CHIPS)...01010100...
5
01101101...
4
00110101...
3
10110111...
2
11011010...
1
...(x CHIPS)... 11111100...
2560 CHIPS
ONE SLOT GROUP
= 5 SLOTS
REAL PART OF SCRAMBLING CODE
GATING
RATE
1/5

FIG. 13C

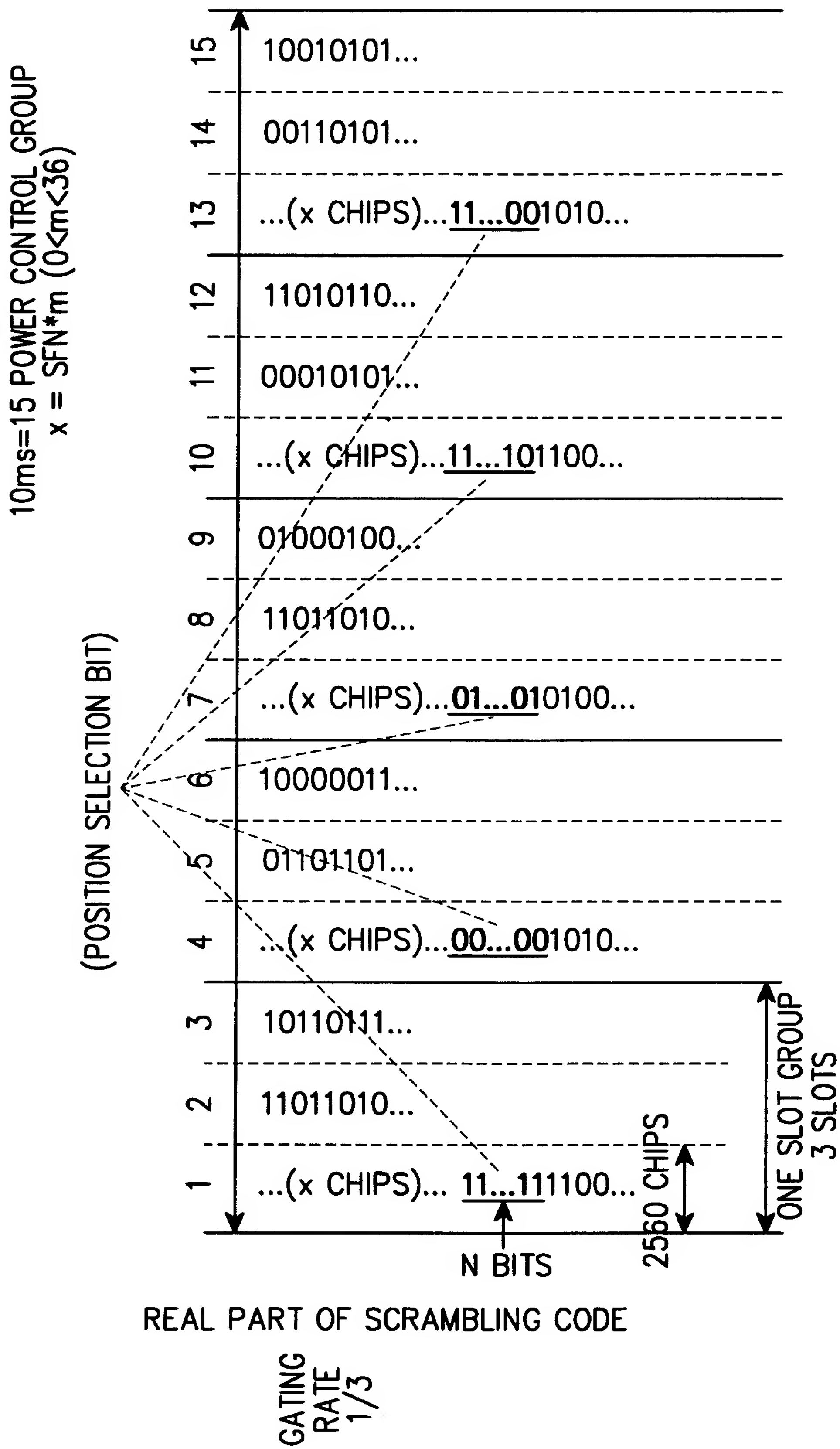

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
(POSITION SELECTION BIT)
15
10010101...
14
00110101...
13
...(x CHIPS)...11...001010...
12
11010110...
11
00010101...
10
...(x CHIPS)...11...101100...
9
01000100...
8
11011010...
7
...(x CHIPS)...01...010100...
6
10000011...
5
01101101...
4
...(x CHIPS)...00...001010...
3
10110111...
2
11011010...
1
...(x CHIPS)... 11...111100...
N BITS
2560 CHIPS
ONE SLOT GROUP
3 SLOTS
REAL PART OF SCRAMBLING CODE
GATING
RATE
1/3

FIG. 13D

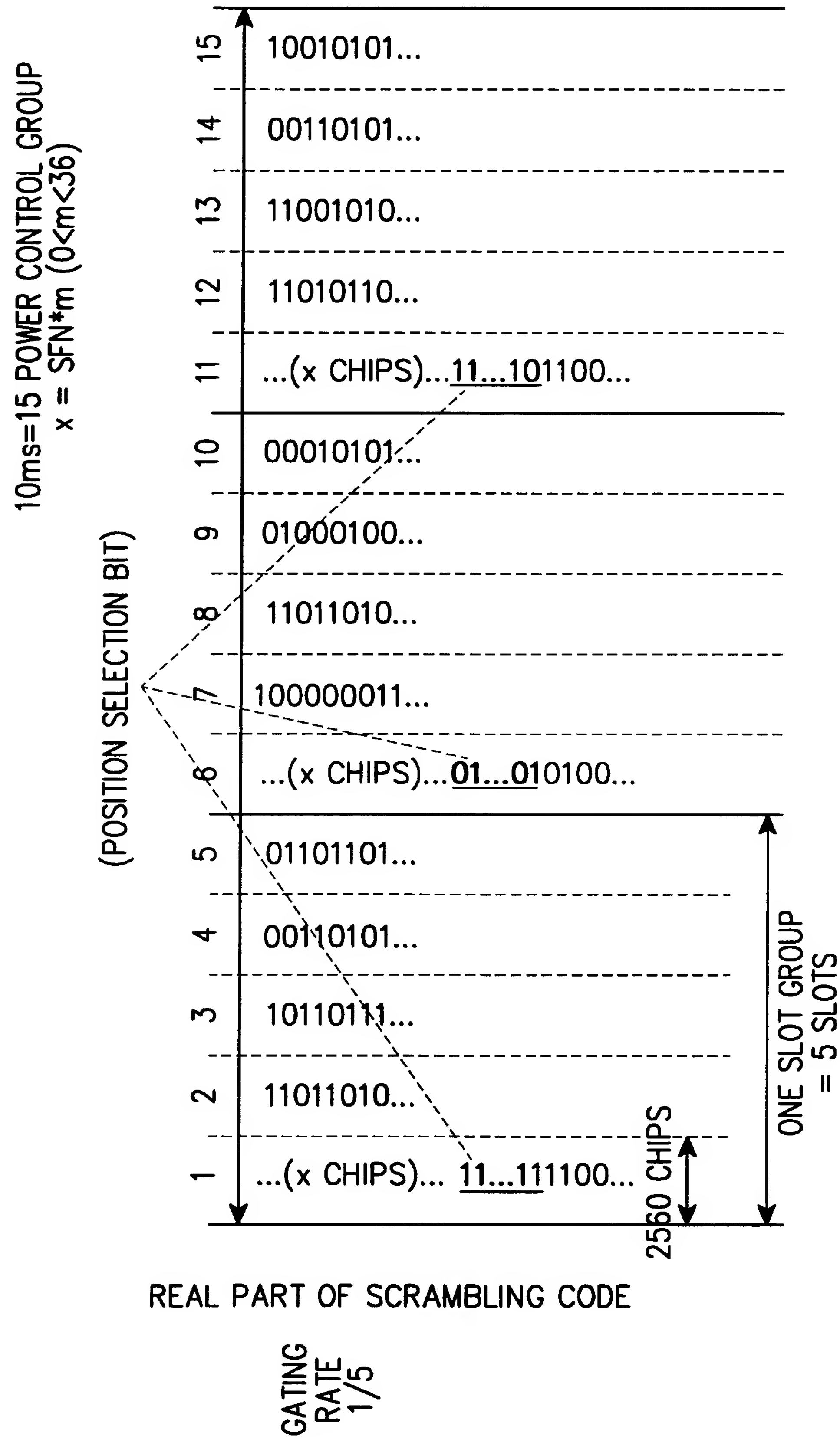

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
(POSITION SELECTION BIT)
15
10010101...
14
00110101...
13
11001010...
12
11010110...
11
...(x CHIPS)...11...101100...
10
00010101...
9
01000100...
8
11011010...
7
100000011...
6
...(x CHIPS)...01...010100...
5
01101101...
4
00110101...
3
10110111...
2
11011010...
1
...(x CHIPS)... 11...111100...
2560 CHIPS
ONE SLOT GROUP = 5 SLOTS
REAL PART OF SCRAMBLING CODE
GATING RATE 1/5

FIG. 14A

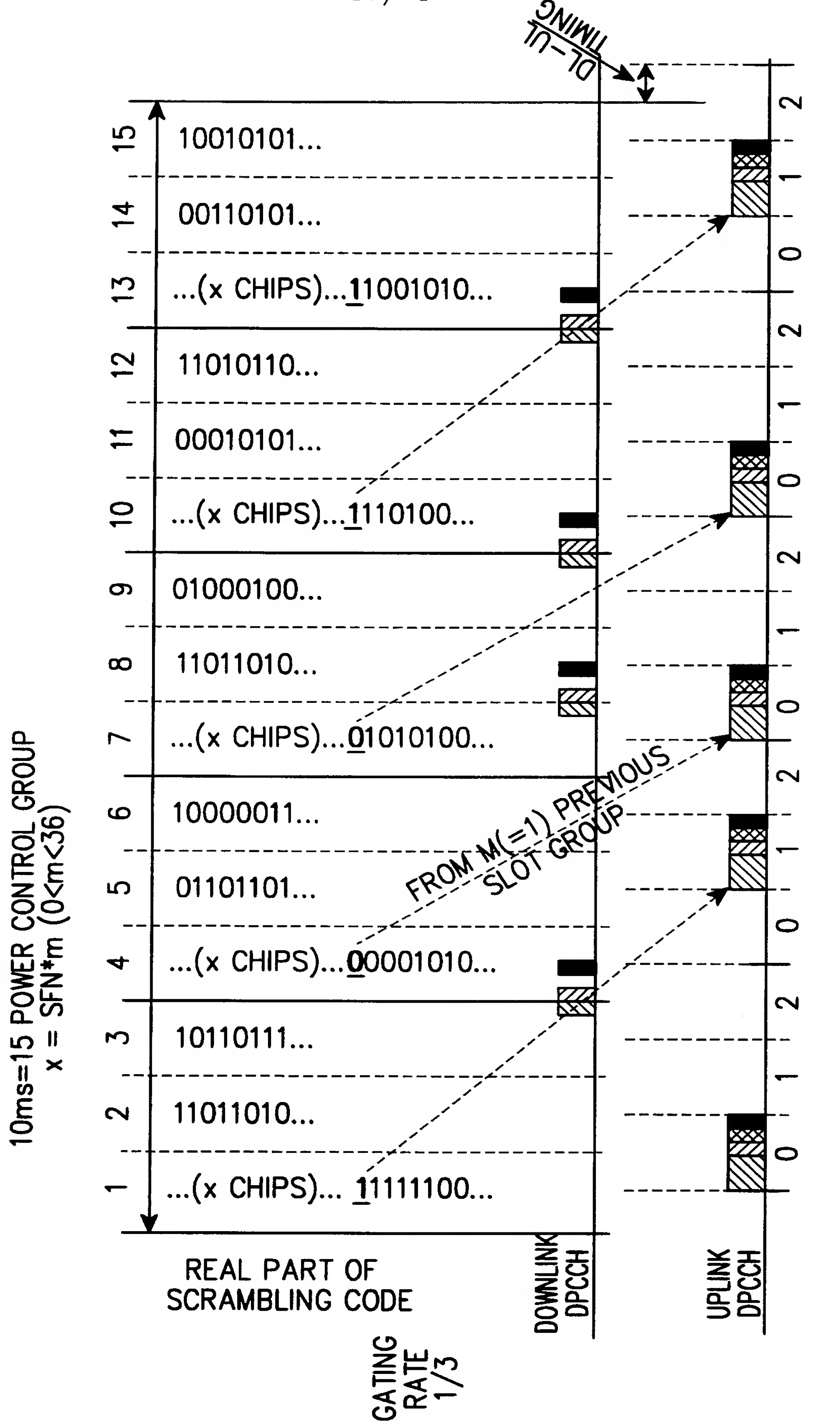

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
...(x CHIPS)... 11111100...
11011010...
10110111...
...(x CHIPS)...00001010...
01101101...
10000011...
...(x CHIPS)...01010100...
11011010...
01000100...
...(x CHIPS)...1110100...
00010101...
11010110...
...(x CHIPS)...11001010...
00110101...
10010101...
DL-UL TIMING
FROM M(=1) PREVIOUS SLOT GROUP
0 1 2 0 1 2 0 1 2 0 1 2 0 1 2
REAL PART OF SCRAMBLING CODE
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/3

FIG. 14B

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)

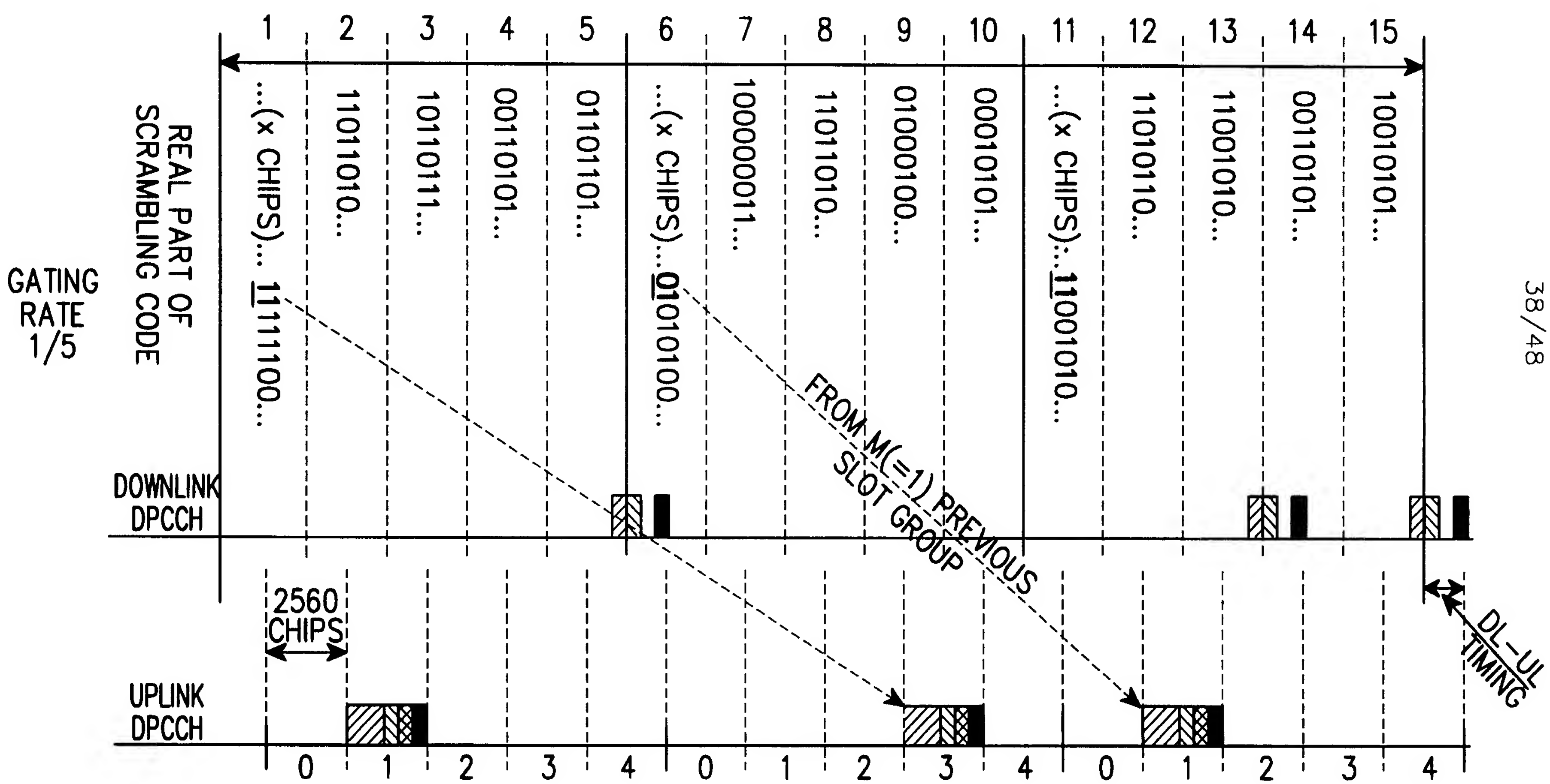


FIG. 14C

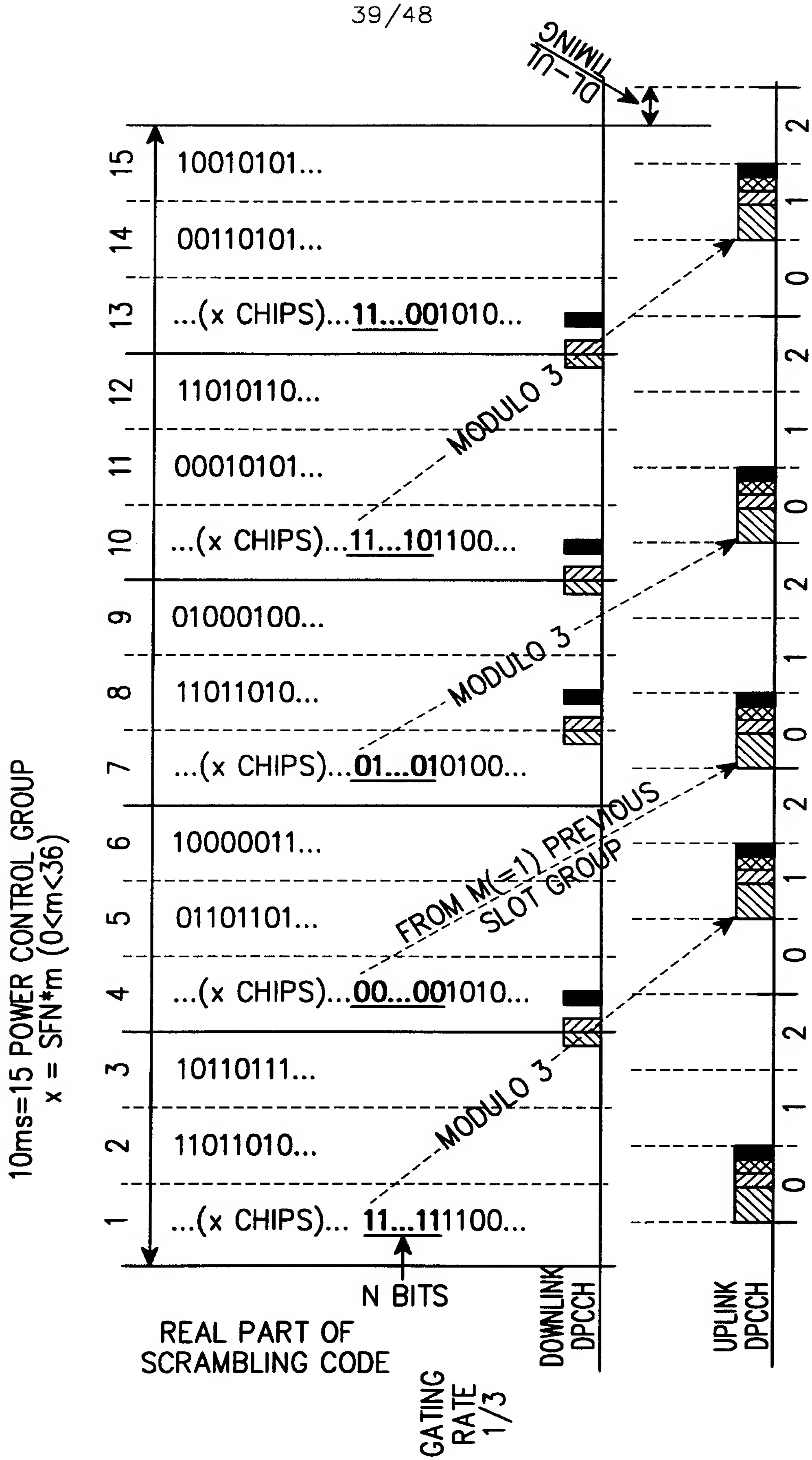

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
DL-UL TIMING
1 ...(x CHIPS)... 11...111100...
2 11011010...
3 10110111...
4 ...(x CHIPS)...00...001010...
5 01101101...
6 10000011...
7 ...(x CHIPS)...01...010100...
8 11011010...
9 01000100...
10 ...(x CHIPS)...11...101100...
11 00010101...
12 11010110...
13 ...(x CHIPS)...11...001010...
14 00110101...
15 10010101...
MODULO 3
MODULO 3
MODULO 3
FROM M(=1) PREVIOUS SLOT GROUP
N BITS
REAL PART OF SCRAMBLING CODE
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/3

FIG. 14D

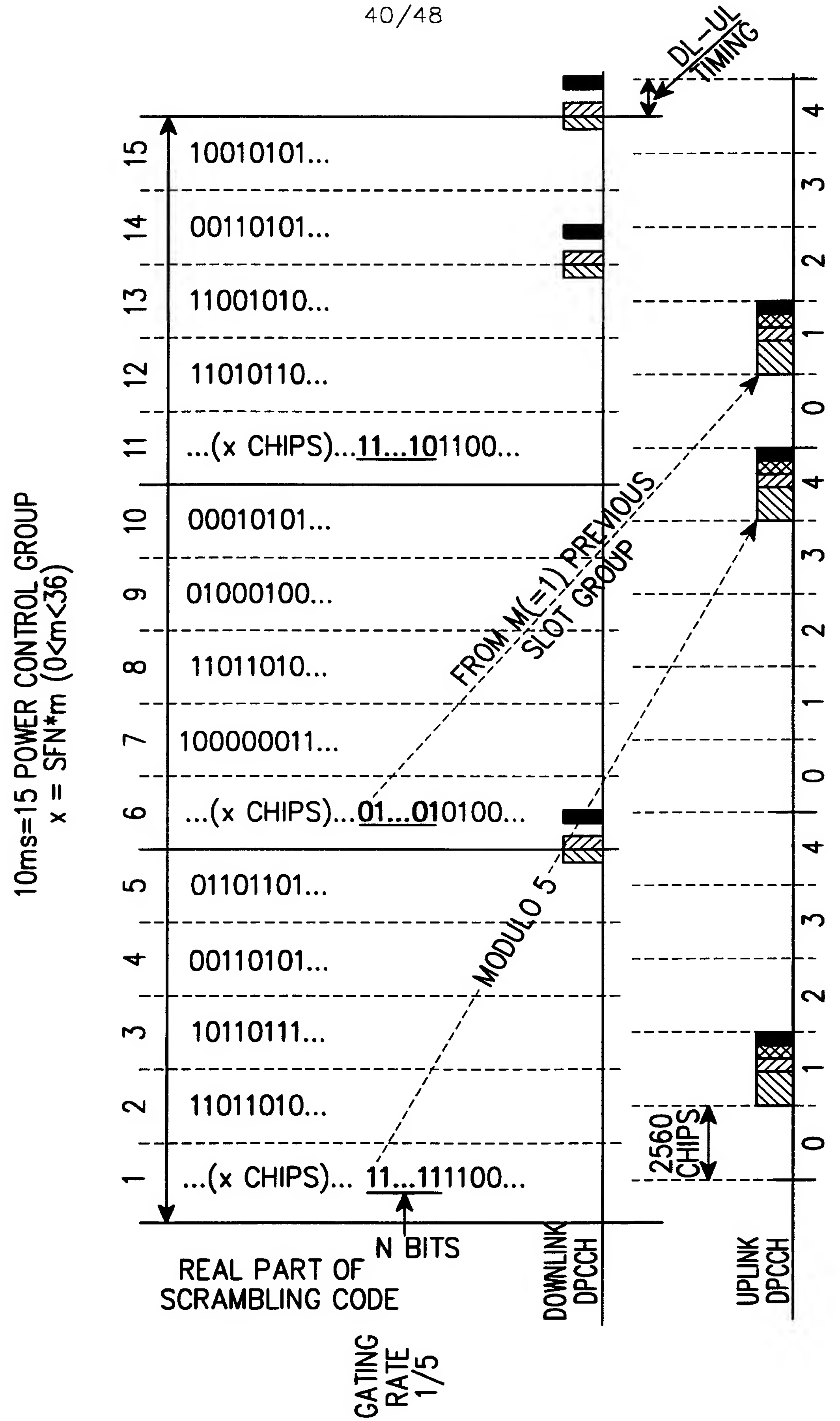

10ms=15 POWER CONTROL GROUP
x = SFN*m (0<m<36)
DL-UL TIMING
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
...(x CHIPS)... 11...111100...
11011010...
10110111...
00110101...
01101101...
...(x CHIPS)...01...010100...
100000011...
11011010...
01000100...
00010101...
...(x CHIPS)...11...101100...
11010110...
11001010...
00110101...
10010101...
FROM M(=1) PREVIOUS SLOT GROUP
MODULO 5
2560 CHIPS
0 1 2 3 4
N BITS
REAL PART OF SCRAMBLING CODE
DOWNLINK DPCCH
UPLINK DPCCH
GATING RATE 1/5

FIG. 15A

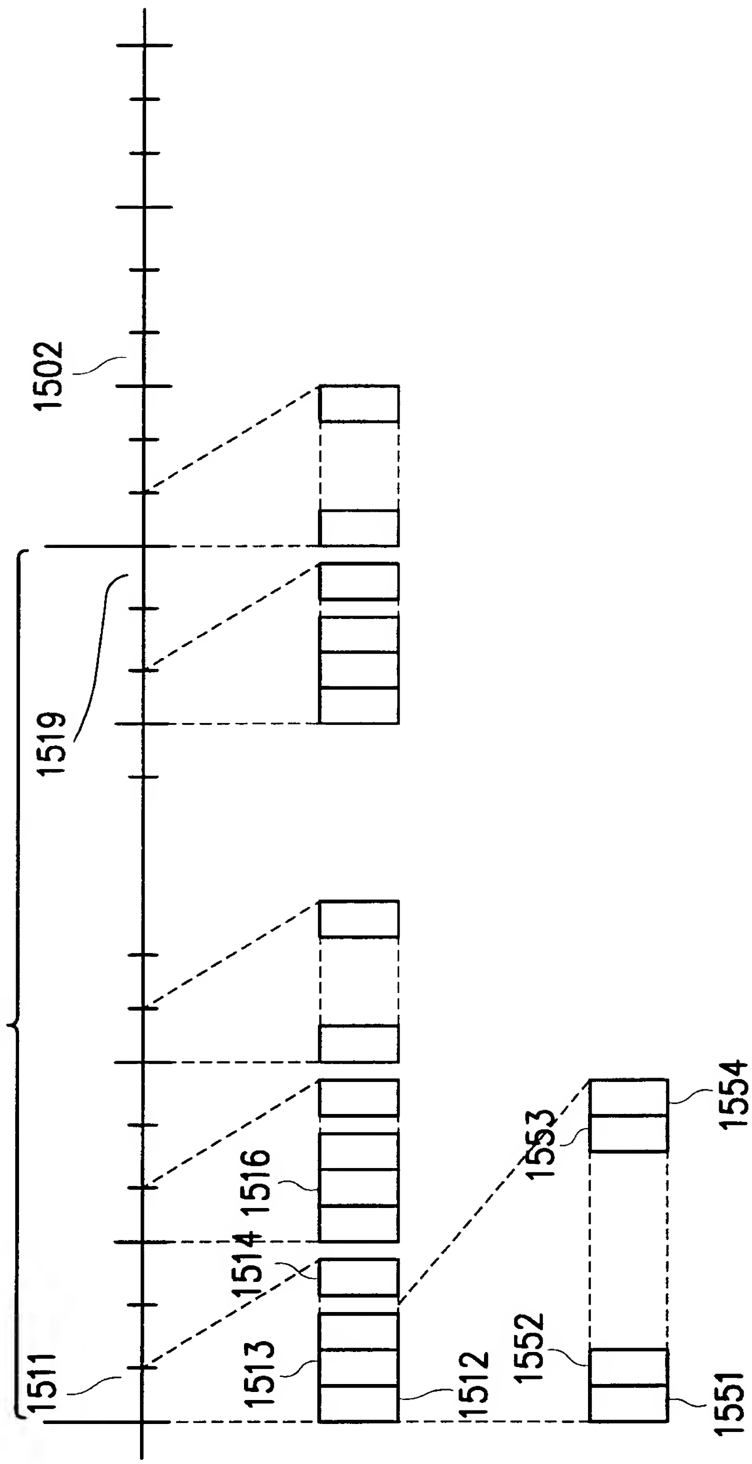


FIG. 15B

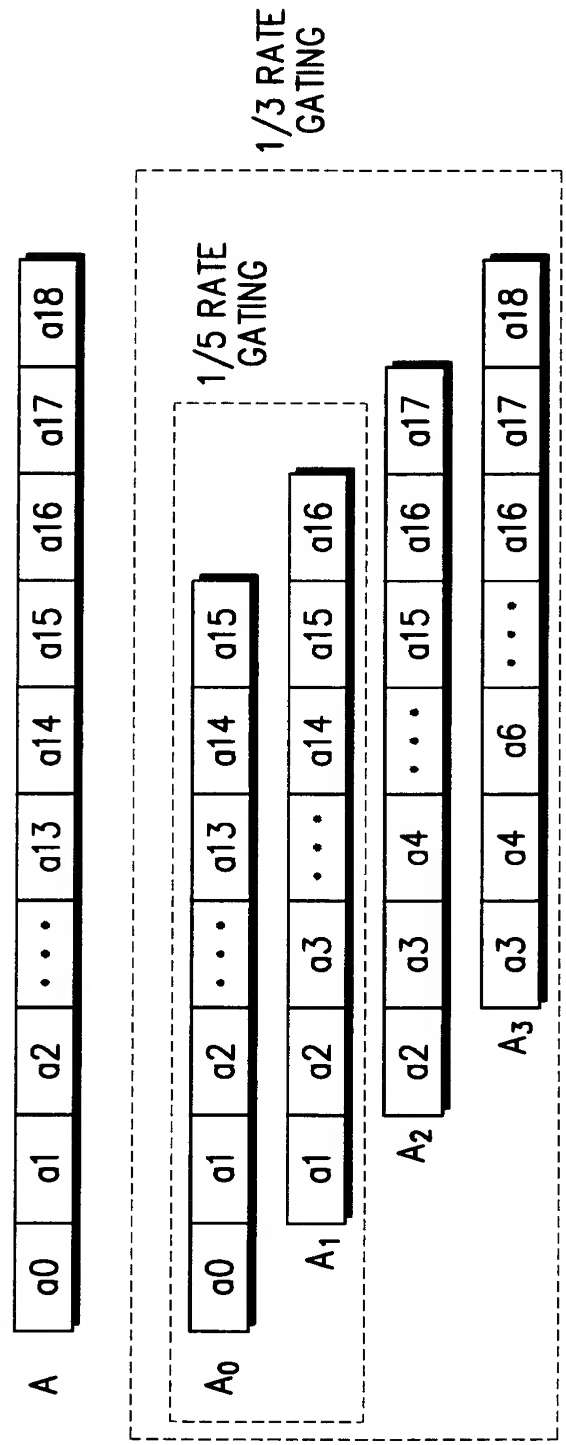

1/3 RATE GATING
1/5 RATE GATING
A
a0
a1
a2
a13
a14
a15
a16
a17
a18
A_0
A_1
a3
A_2
a4
A_3
a6

FIG. 15C

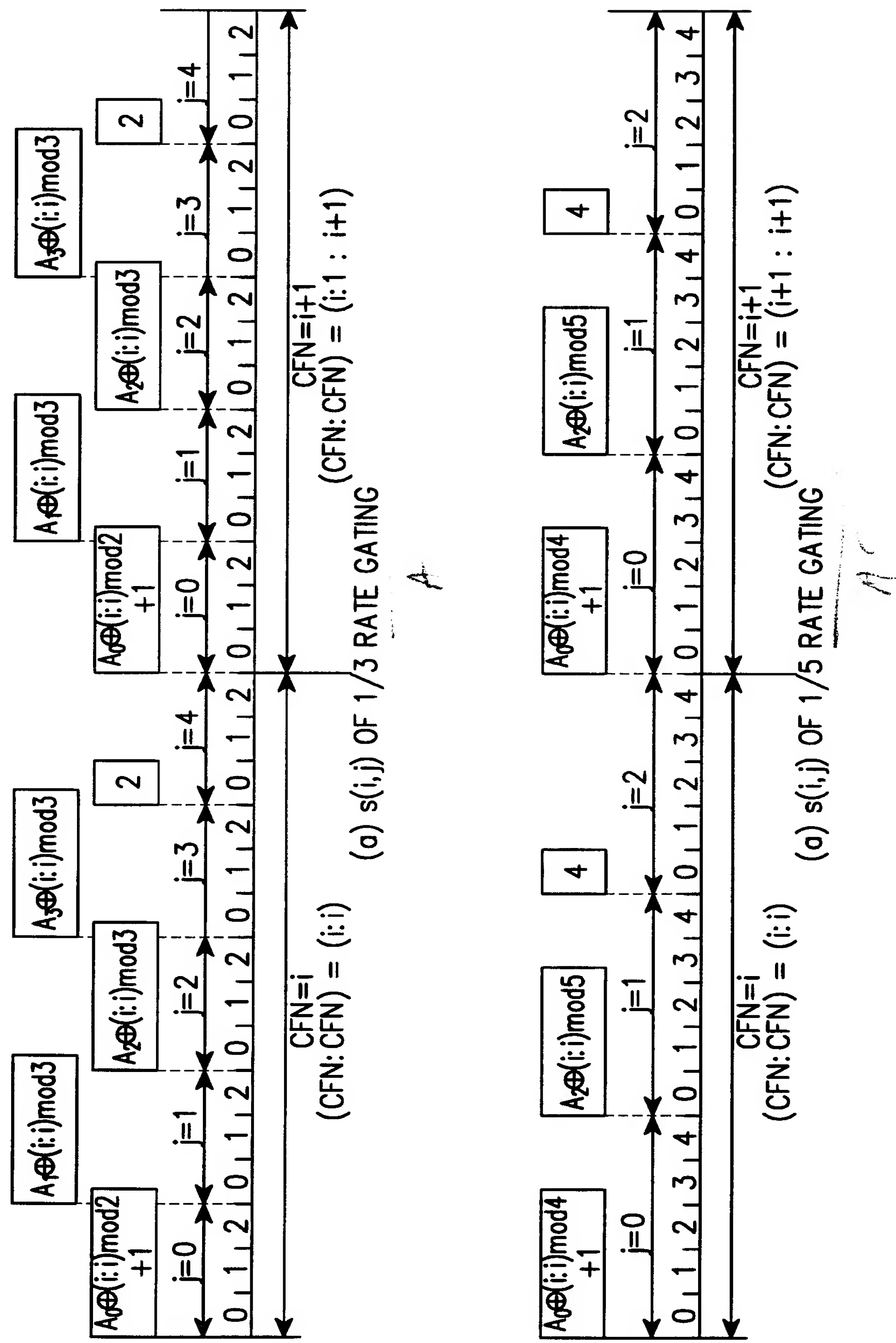

A0⊕(i:i)mod2 +1
A1⊕(i:i)mod3
A2⊕(i:i)mod3
A3⊕(i:i)mod3
2
j=0
j=1
j=2
j=3
j=4
CFN=i
(CFN:CFN) = (i:i)
CFN=i+1
(CFN:CFN) = (i:1 : i+1)
(a) s(i,j) OF 1/3 RATE GATING
A0⊕(i:i)mod4 +1
A2⊕(i:i)mod5
4
(CFN:CFN) = (i+1 : i+1)
(a) s(i,j) OF 1/5 RATE GATING

FIG. 16

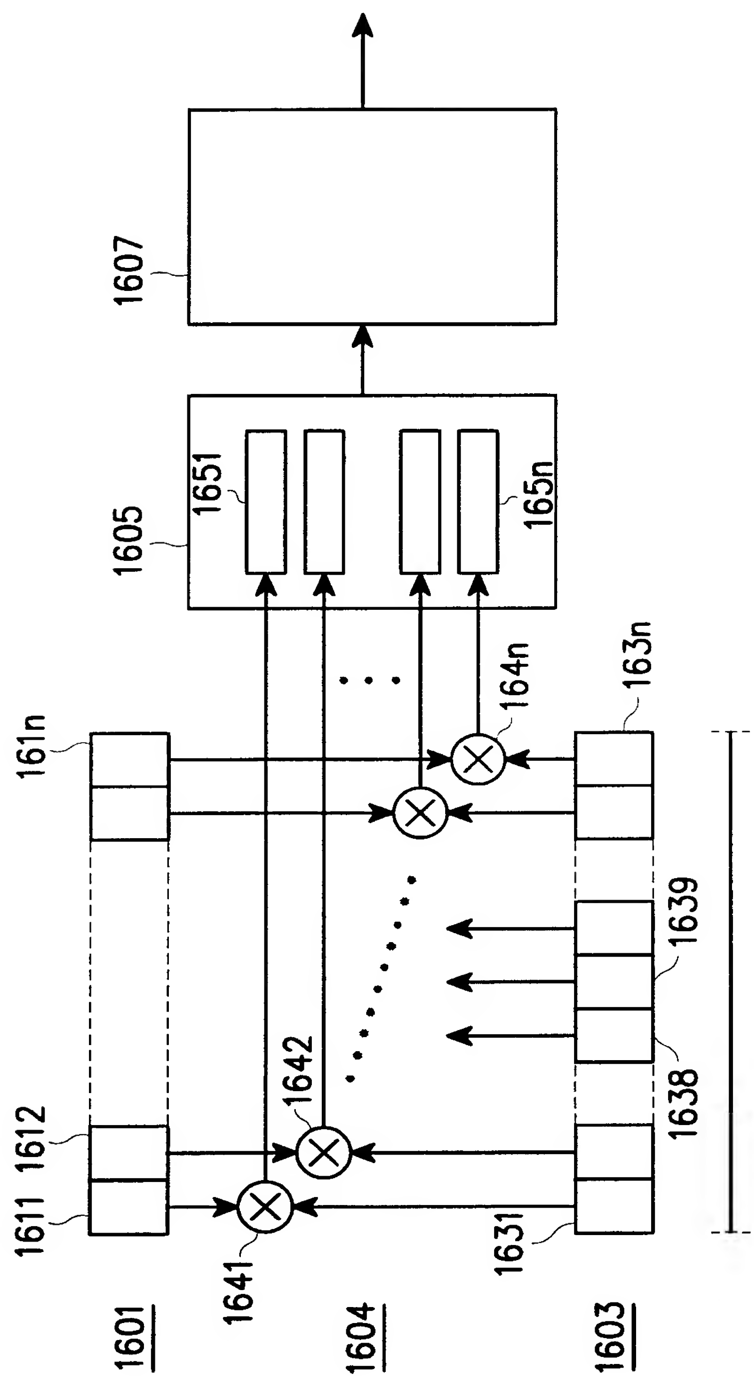

1607
1605
1651
165n
161n
164n
163n
1639
1642
1612
1611
1638
1641
1631
1601
1604
1603

FIG. 17A

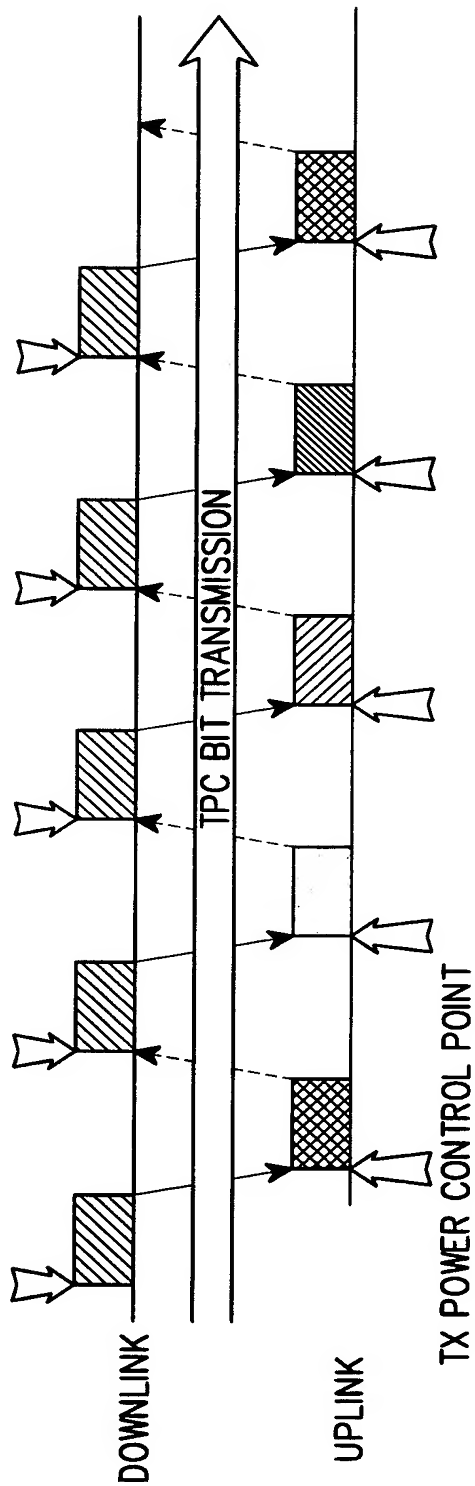

TPC BIT TRANSMISSION
DOWNLINK
UPLINK
TX POWER CONTROL POINT

FIG. 17B

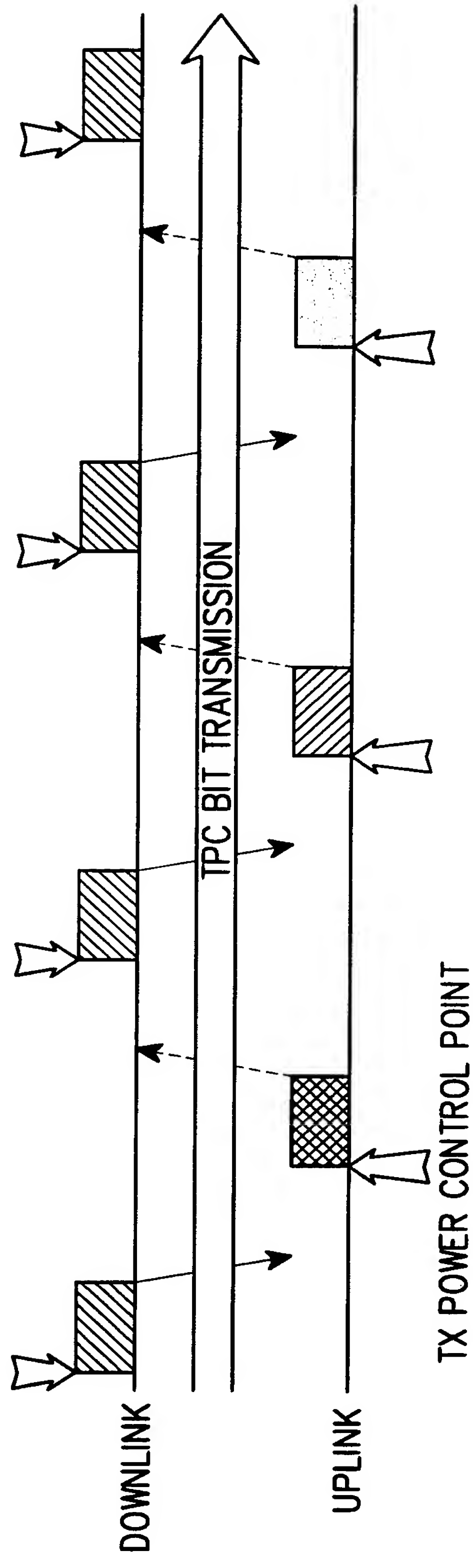

TPC BIT TRANSMISSION
DOWNLINK
UPLINK
TX POWER CONTROL POINT

FIG. 18A

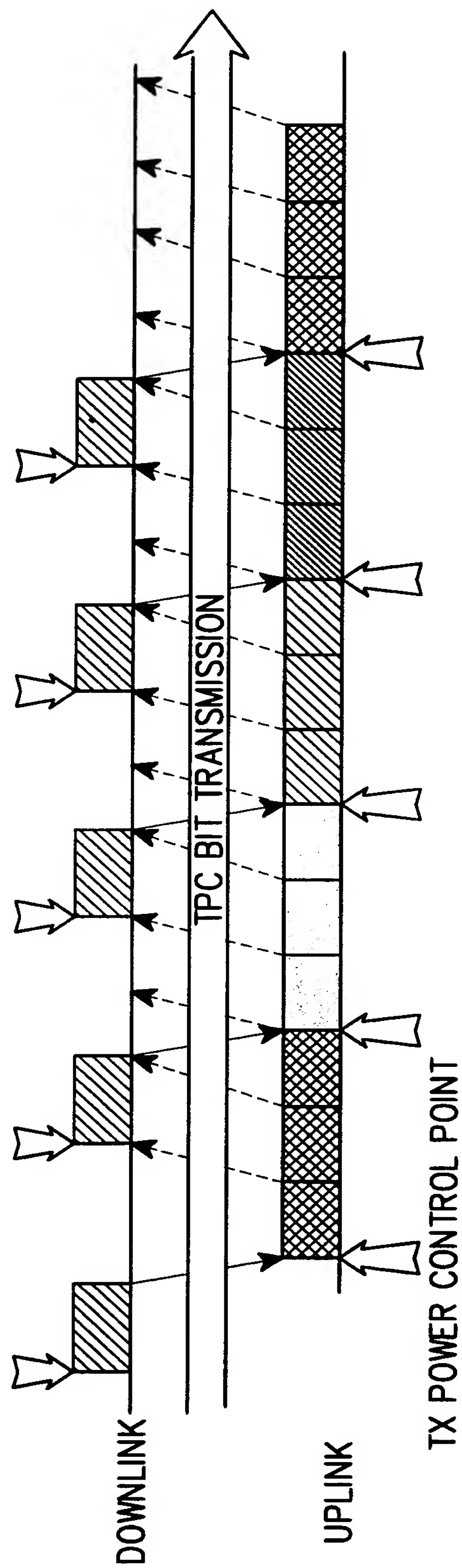
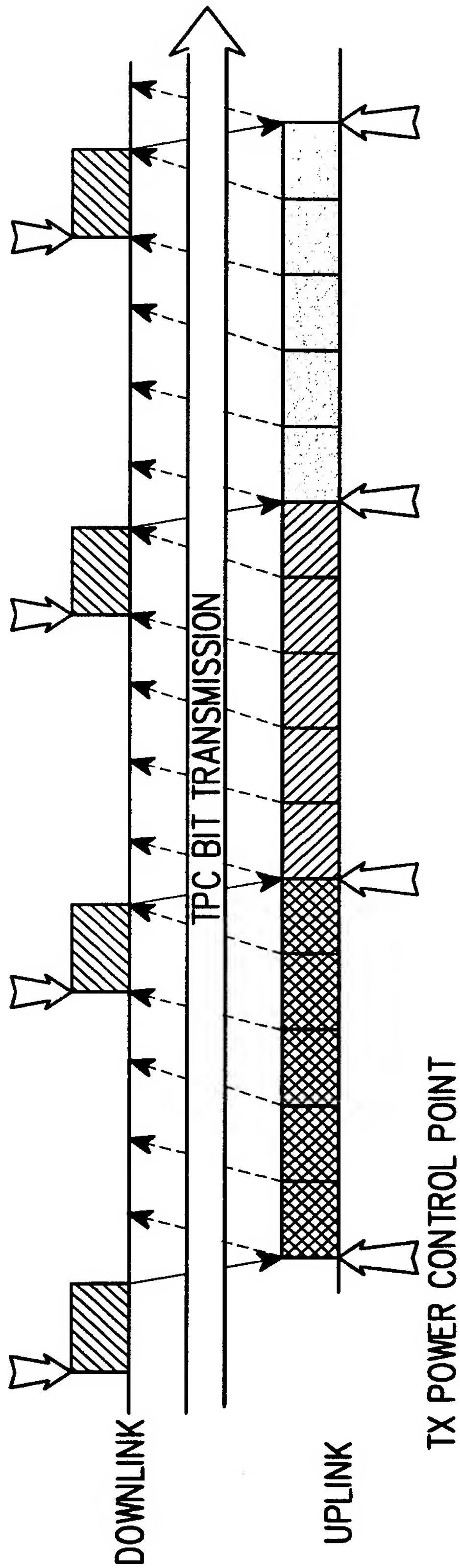

TPC BIT TRANSMISSION
DOWNLINK
UPLINK
TX POWER CONTROL POINT

FIG. 18B


TPC BIT TRANSMISSION
DOWNLINK
UPLINK
TX POWER CONTROL POINT

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR00/01100

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 H04J 13/00, H04B 1/69

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimun documentation searched (classification system followed by classification symbols)
KE, JP, US, EP classes as above

Documentation searched other than minimun documentation to the extent that such documents are included in the fileds searched
Korean Patents and applications for inventions since 1975
Korean Utility models and applications for Utility models since 1975

Electronic data base consulted during the intertnational search (name of data base and, where practicable, search trerms used)
NPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KE 10-89-0001308(General Electric company) 20 MAR. 1989 abstract, claims 1 ~ 12,fig 10, 11	1, 2, 13, 15, 19, 21,27
A	US 4,787,095(Advanced Micro Devices) abstract	1-5, 13,19,21,27-31

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevence; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevence; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 JANUARY 2001 (19.01.2001)	19 JANUARY 2001 (19.01.2001)

Name and mailing address of the ISA/KR	Authorized officer
Korean Industrial Property Office Government Complex-Taejon, Dunsan-dong, So-ku, Taejon Metropolitan City 302-701, Republic of Korea	JEONG, Yong Joo
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(74) Agents: **WADSWORTH, Philip, R.** et al.; Qualcomm Incorporated, 5775 Morehouse Drive, San Diego, CA 92121-1714 (US).

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(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

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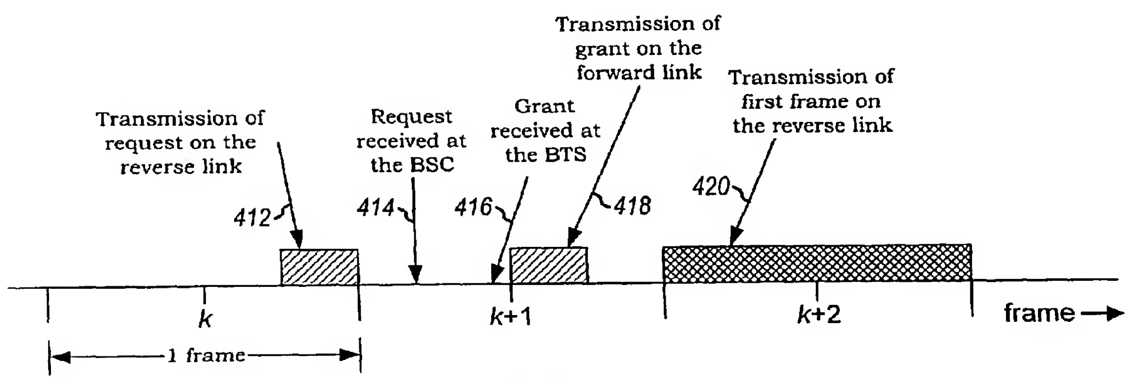
(54) Title: REVERSE LINK CHANNEL ARCHITECTURE FOR A WIRELESS COMMUNICATION SYSTEM



(57) Abstract: A channel structure and mechanisms that support effective and efficient allocation and utilization of the reverse link resources. In one aspect, mechanisms are provided to quickly assign resources (e.g., a supplemental channel) as needed, and to quickly de-assign the resources when not needed or to maintain system stability. The reverse link resources may be quickly assigned and de-assigned via short messages (412, 418) exchanged on control channels on the forward and reverse links. In another aspect, mechanisms are provided to facilitate efficient and reliable data transmission. A reliable acknowledgment/negative acknowledgment scheme and an efficient retransmission scheme are provided. Mechanisms are also provided to control the transmit power and/or data rate of the remote terminals to achieve high performance and avoid instability.

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REVERSE LINK CHANNEL ARCHITECTURE FOR A WIRELESS COMMUNICATION SYSTEM

BACKGROUND

Field

[1001] The present invention relates generally to data communication, and more specifically to a novel and improved reverse link architecture for a wireless communication system.

Background

[1002] Wireless communication systems are widely deployed to provide various types of communication including voice and packet data services. These systems may be based on code division multiple access (CDMA), time division multiple access (TDMA), or some other modulation techniques. CDMA systems may provide certain advantages over other types of system, including increased system capacity.

[1003] In a wireless communication system, a user with a remote terminal (e.g., a cellular phone) communicates with another user through transmissions on the forward and reverse links via one or more base stations. The forward link (i.e., downlink) refers to transmission from the base station to the user terminal, and the reverse link (i.e., uplink) refers to transmission from the user terminal to the base station. The forward and reverse links are typically allocated different frequencies, a method called frequency division multiplexing (FDM).

[1004] The characteristics of packet data transmission on the forward and reverse links are typically very different. On the forward link, the base station usually knows whether or not it has data to transmit, the amount of data, and the identity of the recipient remote terminals. The base station may further be provided with the "efficiency" achieved by each recipient remote terminal, which may be quantified as the amount of transmit power needed per bit. Based on the known information, the base station may be able to efficiently schedule data

transmissions to the remote terminals at the times and data rates selected to achieve the desired performance.

[1005] On the reverse link, the base station typically does not know *a priori* which remote terminals have packet data to transmit, or how much. The base station is typically aware of each received remote terminal's efficiency, which may be quantified by the energy-per-bit-to-total-noise-plus-interface ratio, Ec/(No+Io), needed at the base station to correctly receive a data transmission. The base station may then allocate resources to the remote terminals whenever requested and as available.

[1006] Because of uncertainty in user demands, the usage on the reverse link may fluctuate widely. If many remote terminals transmit at the same time, high interference is generated at the base station. The transmit power from the remote terminals would need to be increased to maintain the target Ec/(No+Io), which would then result in higher levels of interference. If the transmit power is further increased in this manner, a "black out" may ultimately result and the transmissions from all or a large percentage of the remote terminals may not be properly received. This is due to the remote terminal not being able to transmit at sufficient power to close the link to the base station.

[1007] In a CDMA system, the channel loading on the reverse link is often characterized by what is referred to as the "rise-over-thermal". The rise-over-thermal is the ratio of the total received power at a base station receiver to the power of the thermal noise. Based on theoretical capacity calculations for a CDMA reverse link, there is a theoretical curve that shows the rise-over-thermal increasing with loading. The loading at which the rise-over-thermal is infinite is often referred to as the "pole". A loading that has a rise-over-thermal of 3 dB corresponds to a loading of about 50%, or about half of the number of users that can be supported when at the pole. As the number of users increases and as the data rates of the users increase, the loading becomes higher. Correspondingly, as the loading increases, the amount of power that a remote terminal must transmit increases. The rise-over-thermal and channel loading are described in further detail by A.J. Viterbi in "CDMA : Principles of Spread Spectrum Communication," Addison-Wesley Wireless Communications Series, May 1995, ISBN: 0201633744, which is incorporated herein by reference.

[1008] The Viterbi reference provides classical equations that show the relationship between the rise-over-thermal, the number of users, and the data rates of the users. The equations also show that there is greater capacity (in bits/second) if a few users transmit at a high rate than a larger number of users transmit at a higher rate. This is due to the interference between transmitting users.

[1009] In a typical CDMA system, many users' data rates are continuously changing. For example, in an IS-95 or cdma2000 system, a voice user typically transmits at one of four rates, corresponding to the voice activity at the remote terminal, as described in U.S Patent Nos. 5,657,420 and 5,778,338, both entitled "VARIABLE RATE VOCODER" and U.S Patent No. 5,742,734, entitled "ENCODING RATE SELECTION IN A VARIABLE RATE VOCODER". Similarly, many data users are continually varying their data rates. All this creates a considerable amount of variation in the amount of data being transmitted simultaneously, and hence a considerable variation in the rise-over-thermal.

[1010] As can be seen from the above, there is a need in the art for a reverse link channel structure capable of achieving high performance for packet data transmission, and which takes into consideration the data transmission characteristics of the reverse links.

SUMMARY

[1011] Aspects of the invention provide mechanisms that support effective and efficient allocation and utilization of the reverse link resources. In one aspect, mechanisms are provided to quickly assign resources (e.g., supplemental channels) as needed, and to quickly de-assign the resources when not needed or to maintain system stability. The reverse link resources may be quickly assigned and de-assigned via short messages exchanged on control channels on the forward and reverse links. In another aspect, mechanisms are provided to facilitate efficient and reliable data transmission. In particular, a reliable acknowledgment/negative acknowledgment scheme and an efficient retransmission scheme are provided. In yet another aspect,

mechanisms are provided to control the transmit power and/or data rate of the remote terminals to achieve high performance and avoid instability. Another aspect of the invention provides a channel structure capable of implementing the features described above. These and other aspects are described in further detail below.

[1012] The disclosed embodiments further provide methods, channel structures, and apparatus that implement various aspects, embodiments, and features of the invention, as described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[1013] The features, nature, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

[1014] FIG. 1 is a diagram of a wireless communication system that supports a number of users;

[1015] FIG. 2 is a simplified block diagram of an embodiment of a base station and a remote terminal;

[1016] FIGS. 3A and 3B are diagrams of a reverse and a forward channel structure, respectively;

[1017] FIG. 4 is a diagram illustrating a communication between the remote terminal and base station to assign a reverse link supplemental channel (R-SCH);

[1018] FIGS. 5A and 5B are diagrams illustrating a data transmission on the reverse link and an Ack/Nak message transmission for two different scenarios;

[1019] FIGS. 6A and 6B are diagrams illustrating an acknowledgment sequencing with short and long acknowledgment delays, respectively;

[1020] FIG. 7 is a flow diagram that illustrates a variable rate data transmission on the R-SCH with fast congestion control, in accordance with an embodiment of the invention; and

[1021] FIG. 8 is a diagram illustrating improvement that may be possible with fast control of the R-SCH.

DETAILED DESCRIPTION

[1022] FIG. 1 is a diagram of a wireless communication system 100 that supports a number of users and capable of implementing various aspects of the invention. System 100 provides communication for a number of cells, with each cell being serviced by a corresponding base station 104. The base stations are also commonly referred to as base transceiver systems (BTSs). Various remote terminals 106 are dispersed throughout the system. Each remote terminal 106 may communicate with one or more base stations 104 on the forward and reverse links at any particular moment, depending on whether or not the remote terminal is active and whether or not it is in soft handoff. The forward link refers to transmission from base station 104 to remote terminal 106, and the reverse link refers to transmission from remote terminal 106 to base station 104. As shown in FIG. 1, base station 104a communicates with remote terminals 106a, 106b, 106c, and 106d, and base station 104b communicates with remote terminals 106d, 106e, and 106f. Remote terminal 106d is in soft handoff and concurrently communicates with base stations 104a and 104b.

[1023] In system 100, a base station controller (BSC) 102 couples to base stations 104 and may further couple to a public switched telephone network (PSTN). The coupling to the PSTN is typically achieved via a mobile switching center (MSC), which is not shown in FIG. 1 for simplicity. The BSC may also couple into a packet network, which is typically achieved via a packet data serving node (PDSN) that is also not shown in FIG. 1. BSC 102 provides coordination and control for the base stations coupled to it. BSC 102 further controls the routing of telephone calls among remote terminals 106, and between remote terminals 106 and users coupled to the PSTN (e.g., conventional telephones) and to the packet network, via base stations 104.

[1024] System 100 may be designed to support one or more CDMA standards such as (1) the "TIA/EIA-95-B Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System" (the IS-95 standard), (2) the "TIA/EIA-98-D Recommended Minimum Standard for Dual-Mode Wideband Spread Spectrum Cellular Mobile Station"

(the IS-98 standard), (3) the documents offered by a consortium named "3rd Generation Partnership Project" (3GPP) and embodied in a set of documents including Document Nos. 3G TS 25.211, 3G TS 25.212, 3G TS 25.213, and 3G TS 25.214 (the W-CDMA standard), (4) the documents offered by a consortium named "3rd Generation Partnership Project 2" (3GPP2) and embodied in a set of documents including Document Nos. C.S0002-A, C.S0005-A, C.S0010-A, C.S0011-A. C.S0024, and C.S0026 (the cdma2000 standard), and (5) some other standards. In the case of the 3GPP and 3GPP2 documents, these are converted by standards bodies worldwide (e.g., TIA, ETSI, ARIB, TTA, and CWTS) into regional standards and have been converted into international standards by the International Telecommunications Union (ITU). These standards are incorporated herein by reference.

[1025] FIG. 2 is a simplified block diagram of an embodiment of base station 104 and remote terminal 106, which are capable of implementing various aspects of the invention. For a particular communication, voice data, packet data, and/or messages may be exchanged between base station 104 and remote terminal 106. Various types of messages may be transmitted such as messages used to establish a communication session between the base station and remote terminal and messages used to control a data transmission (e.g., power control, data rate information, acknowledgment, and so on). Some of these message types are described in further detail below.

[1026] For the reverse link, at remote terminal 106, voice and/or packet data (e.g., from a data source 210) and messages (e.g., from a controller 230) are provided to a transmit (TX) data processor 212, which formats and encodes the data and messages with one or more coding schemes to generate coded data. Each coding scheme may include any combination of cyclic redundancy check (CRC), convolutional, Turbo, block, and other coding, or no coding at all. Typically, voice data, packet data, and messages are coded using different schemes, and different types of message may also be coded differently.

[1027] The coded data is then provided to a modulator (MOD) 214 and further processed (e.g., covered, spread with short PN sequences, and scrambled with a long PN sequence assigned to the user terminal). The modulated data is then provided to a transmitter unit (TMTR) 216 and

conditioned (e.g., converted to one or more analog signals, amplified, filtered, and quadrature modulated) to generate a reverse link signal. The reverse link signal is routed through a duplexer (D) 218 and transmitted via an antenna 220 to base station 104.

[1028] At base station 104, the reverse link signal is received by an antenna 250, routed through a duplexer 252, and provided to a receiver unit (RCVR) 254. Receiver unit 254 conditions (e.g., filters, amplifies, downconverts, and digitizes) the received signal and provides samples. A demodulator (DEMOD) 256 receives and processes (e.g., despreads, decovers, and pilot demodulates) the samples to provide recovered symbols. Demodulator 256 may implement a rake receiver that processes multiple instances of the received signal and generates combined symbols. A receive (RX) data processor 258 then decodes the symbols to recover the data and messages transmitted on the reverse link. The recovered voice/packet data is provided to a data sink 260 and the recovered messages may be provided to a controller 270. The processing by demodulator 256 and RX data processor 258 are complementary to that performed at remote terminal 106. Demodulator 256 and RX data processor 258 may further be operated to process multiple transmissions received via multiple channels, e.g., a reverse fundamental channel (R-FCH) and a reverse supplemental channel (R-SCH). Also, transmissions may be received simultaneously from multiple remote terminals, each of which may be transmitting on a reverse fundamental channel, a reverse supplemental channel, or both.

[1029] On the forward link, at base station 104, voice and/or packet data (e.g., from a data source 262) and messages (e.g., from controller 270) are processed (e.g., formatted and encoded) by a transmit (TX) data processor 264, further processed (e.g., covered and spread) by a modulator (MOD) 266, and conditioned (e.g., converted to analog signals, amplified, filtered, and quadrature modulated) by a transmitter unit (TMTR) 268 to generate a forward link signal. The forward link signal is routed through duplexer 252 and transmitted via antenna 250 to remote terminal 106.

[1030] At remote terminal 106, the forward link signal is received by antenna 220, routed through duplexer 218, and provided to a receiver unit 222.

Receiver unit 222 conditions (e.g., downconverts, filters, amplifies, quadrature demodulates, and digitizes) the received signal and provides samples. The samples are processed (e.g., despreaded, decovered, and pilot demodulated) by a demodulator 224 to provide symbols, and the symbols are further processed (e.g., decoded and checked) by a receive data processor 226 to recover the data and messages transmitted on the forward link. The recovered data is provided to a data sink 228, and the recovered messages may be provided to controller 230.

[1031] The reverse link has some characteristics that are very different from those of the forward link. In particular, the data transmission characteristics, soft handoff behaviors, and fading phenomenon are typically very different between the forward and reverse links.

[1032] As noted above, on the reverse link, the base station typically does not know *a priori* which remote terminals have packet data to transmit, or how much. Thus, the base station may allocate resources to the remote terminals whenever requested and as available. Because of uncertainty in user demands, the usage on the reverse link may fluctuate widely.

[1033] In accordance with aspects of the invention, mechanisms are provided to effectively and efficiently allocate and utilize the reverse link resources. In one aspect, mechanisms are provided to quickly assign resources as needed, and to quickly de-assign resources when not needed or to maintain system stability. The reverse link resources may be assigned via a supplemental channel that is used for packet data transmission. In another aspect, mechanisms are provided to facilitate efficient and reliable data transmission. In particular, a reliable acknowledgment scheme and an efficient retransmission scheme are provided. In yet another aspect, mechanisms are provided to control the transmit power of the remote terminals to achieve high performance and avoid instability. These and other aspects are described in further detail below.

[1034] FIG. 3A is a diagram of an embodiment of a reverse channel structure capable of implementing various aspects of the invention. In this embodiment, the reverse channel structure includes an access channel, an enhanced access channel, a pilot channel (R-PICH), a common control channel (R-CCCH), a

dedicated control channel (R-DCCH), a fundamental channel (R-FCH), supplemental channels (R-SCH), and a reverse rate indicator channel (R-RICH). Different, fewer, and/or additional channels may also be supported and are within the scope of the invention. These channels may be implemented similar to those defined by the cdma2000 standard. Features of some of these channels are described below.

[1035] For each communication (i.e., each call), a specific set of channels that may be used for the communication and their configurations are defined by one of a number of radio configurations (RC). Each RC defines a specific transmission format, which is characterized by various physical layer parameters such as, for example, the transmission rates, modulation characteristics, spreading rate, and so on. The radio configurations may be similar to those defined for the cdma2000 standard.

[1036] The reverse dedicated control channel (R-DCCH) is used to transmit user and signaling information (e.g., control information) to the base station during a communication. The R-DCCH may be implemented similar to the R-DCCH defined in the cdma2000 standard.

[1037] The reverse fundamental channel (R-FCH) is used to transmit user and signaling information (e.g., voice data) to the base station during a communication. The R-FCH may be implemented similar to the R-FCH defined in the cdma2000 standard.

[1038] The reverse supplemental channel (R-SCH) is used to transmit user information (e.g., packet data) to the base station during a communication. The R-SCH is supported by some radio configurations (e.g., RC3 through RC11), and is assigned to the remote terminals as needed and if available. In an embodiment, zero, one, or two supplemental channels (i.e., R-SCH1 and R-SCH2) may be assigned to the remote terminal at any given moment. In an embodiment, the R-SCH supports retransmission at the physical layer, and may utilize different coding schemes for the retransmission. For example, a retransmission may use a code rate of 1/2 for the original transmission. The same rate 1/2 code symbols may be repeated for the retransmission. In an alternative embodiment, the underlying code may be a rate 1/4 code. The original transmission may use 1/2 of the symbols and the retransmission may

use the other half of the symbols. If a third retransmission is done, it can repeat one of the group of symbols, part of each group, a subset of either group, and other possible combinations of symbols.

[1039] R-SCH2 may be used in conjunction with R-SCH1 (e.g., for RC11). In particular, R-SCH2 may be used to provide a different quality of service (QoS). Also, Type II and III hybrid ARQ schemes may be used in conjunction with the R-SCH. Hybrid ARQ schemes are generally described by S.B. Wicker in "Error Control System for Digital Communication and Storage," Prentice-Hall, 1995, Chapter 15, which is incorporated herein by reference. Hybrid ARQ schemes are also described in the cdma2000 standard.

[1040] The reverse rate indicator channel (R-RICH) is used by the remote terminal to provide information pertaining to the (packet) transmission rate on one or more reverse supplemental channels. Table 1 lists the fields for a specific format of the R-RICH. In an embodiment, for each data frame transmission on the R-SCH, the remote terminal sends a reverse rate indicator (RRI) symbol, which indicates the data rate for the data frame. The remote terminal also sends the sequence number of the data frame being transmitted, and whether the data frame is a first transmission or a retransmission. Different, fewer, and/or additional fields may also be used for the R-RICH and are within the scope of the invention. The information in Table 1 is sent by the remote terminal for each data frame transmitted on the supplemental channel (e.g., each 20 msec).

Table 1

Field	Length (bits)
RRI	3
SEQUENCE_NUM	2
RETRAN_NUM	2

[1041] If there are multiple reverse supplemental channels (e.g., R-SCH1 and R-SCH2), then there can be multiple R-RICH channels (e.g., R-RICH1 and R-RICH2), each with the RRI, SEQUENCE_NUM, and RETRAN_NUM fields. Alternatively, the fields for multiple reverse supplemental channels may be

combined into a single R-RICH channel. In a particular embodiment, the RRI field is not used, and fixed transmission rates are used or the base station performs blind rate determination in which the base determines the transmission rate from the data. Blind rate determination may be achieved in a manner described in U.S Patent No. 6,175,590, entitled "METHOD AND APPARATUS FOR DETERMINING THE RATE OF RECEIVED DATA IN A VARIABLE RATE COMMUNICATION SYSTEM," issued January 16, 2001, U.S Patent No. 5,751,725, entitled "METHOD AND APPARATUS FOR DETERMINING THE RATE OF RECEIVED DATA IN A VARIABLE RATE COMMUNICATION SYSTEM," issued May 12, 1998, both of which are assigned to the assignee of the present application and incorporated herein by reference.

[1042] FIG. 3B is a diagram of an embodiment of a forward channel structure capable of supporting various aspects of the invention. In this embodiment, the forward channel structure includes common channels, pilot channels, and dedicated channels. The common channels include a broadcast channel (F-BCCH), a quick paging channel (F-QPCH), a common control channel (F-CCCH), and a common power control channel (F-CPCCH). The pilot channels include a basic pilot channel and an auxiliary pilot channel. And the dedicated channels include a fundamental channel (F-FCH), a supplemental channel (F-SCH), a dedicated auxiliary channel (F-APICH), a dedicated control channel (F-DCCH), and a dedicated packet control channel (F-CPDCCH). Again, different, fewer, and/or additional channels may also be supported and are within the scope of the invention. These channels may be implemented similar to those defined by the cdma2000 standard. Features of some of these channels are described below.

[1043] The forward common power control channel (F-CPCCH) is used by the base station to transmit power control subchannels (e.g., one bit per subchannel) for power control of the R-PICH, R-FCH, R-DCCH, and R-SCH. In an embodiment, upon channel assignment, a remote terminal is assigned a reverse link power control subchannel from one of three sources - the F-DCCH, F-SCH, and F-CPCCH. The F-CPCCH may be assigned if the reverse link power control subchannel is not provided from either the F-DCCH or F-SCH.

[1044] In an embodiment, the available bits in the F-CPCCH may be used to form one or more power control subchannels, which may then be assigned for different uses. For example, a number of power control subchannels may be defined and used for power control of a number of reverse link channels. Power control for multiple channels based on multiple power control subchannels may be implemented as described in U.S. Patent No. 5,991,284, entitled "SUBCHANNEL POWER CONTROL," issued November 23, 1999, assigned to the assignee of the present application and incorporated herein by reference.

[1045] In one specific implementation, an 800 bps power control subchannel controls the power of the reverse pilot channel (R-PICH). All reverse traffic channels (e.g., the R-FCH, R-DCCH, and R-SCH) have their power levels related to the R-PICH by a known relationship, e.g., as described in C.S0002. The ratio between two channels is often referred to as the traffic-to-pilot ratio. The traffic-to-pilot ratio (i.e., the power level of the reverse traffic channel relative to the R-PICH) can be adjusted by messaging from the base station. However, this messaging is slow, so a 100 bits/second (bps) power control subchannel may be defined and used for power control of the R-SCH. In an embodiment, this R-SCH power control subchannel controls the R-SCH relative to the R-PICH. In another embodiment, the R-SCH power control subchannel controls the absolute transmission power of the R-SCH.

[1046] In an aspect of the invention, a "congestion" control subchannel may also be defined for control of the R-SCH, and this congestion control subchannel may be implemented based on the R-SCH power control subchannel or another subchannel.

[1047] Power control for the reverse link is described in further detail below.

[1048] The forward dedicated packet control channel (F-DPCCH) is used to transmit user and signaling information to a specific remote terminal during a communication. The F-DPCCH may be used to control a reverse link packet data transmission. In an embodiment, the F-DPCCH is encoded and interleaved to enhance reliability, and may be implemented similar to the F-DCCH defined by the cdma2000 standard.

[1049] Table 2 lists the fields for a specific format of the F-DPCCH. In an embodiment, the F-DPCCH has a frame size of 48 bits, of which 16 are used for CRC, 8 bits are used for the encoder tail, and 24 bits are available for data and messaging. In an embodiment, the default transmission rate for the F-DPCCH is 9600 bps, in which case a 48-bit frame can be transmitted in 5 msec time interval. In an embodiment, each transmission (i.e., each F-DPCCH frame) is covered with a public long code of the recipient remote terminal to which the frame is targeted. This avoids the need to use an explicit address (hence, the channel is referred to as a "dedicated" channel). However, the F-DPCCH is also "common" since a large number of remote terminals in dedicated channel mode may continually monitor the channel. If a message is directed to a particular remote terminal and is received correctly, then the CRC will check.

Table 2

Field	Number of Bits / Frame
Information	24
Frame Quality Indicator	16
Encoder Tail	8

[1050] The F-DPCCH may be used to transmit mini-messages, such as the ones defined by the cdma2000 standard. For example, the F-DPCCH may be used to transmit a *Reverse Supplemental Channel Assignment Mini Message* (RSCAMM) used to grant the F-SCH to the remote terminal.

[1051] The forward common packet Ack/Nak channel (F-CPANCH) is used by the base station to transmit (1) acknowledgments (Ack) and negative acknowledgments (Nak) for a reverse link packet data transmission and (2) other control information. In an embodiment, acknowledgments and negative acknowledgments are transmitted as n-bit Ack/Nak messages, with each message being associated with a corresponding data frame transmitted on the reverse link. In an embodiment, each Ack/Nak message may include 1, 2, 3, or 4 bits (or possible more bits), with the number of bits in the message being dependent on the number of reverse link channels in the service configuration.

The n-bit Ack/Nak message may be block coded to increase reliability or transmitted in the clear.

[1052] In an aspect, to improve reliability, the Ack/Nak message for a particular data frame is retransmitted in a subsequent frame (e.g., 20 msec later) to provide time diversity for the message. The time diversity provides additional reliability, or may allow for the reduction in power used to send the Ack/Nak message while maintaining the same reliability. The Ack/Nak message may use error correcting coding as is well known in the art. For the retransmission, the Ack/Nak message may repeat the exact same code word or may use incremental redundancy. Transmission and retransmission of the Ack/Nak is described in further detail below.

[1053] Several types of control are used on the forward link to control the reverse link. These include controls for supplemental channel request and grant, Ack/Nak for a reverse link data transmission, power control of the data transmission, and possibly others.

[1054] The reverse link may be operated to maintain the rise-over-thermal at the base station relatively constant as long as there is reverse link data to be transmitted. Transmission on the R-SCH may be allocated in various ways, two of which are described below:

- By infinite allocation. This method is used for real-time traffic that cannot tolerate much delay. The remote terminal is allowed to transmit immediately up to a certain allocated data rate.
- By scheduling. The remote terminal sends an estimate of its buffer size. The base station determines when the remote terminal is allowed to transmit. This method is used for available bit rate traffic. The goal of a scheduler is to limit the number of simultaneous transmissions so that the number of simultaneously transmitting remote terminals is limited, thus reducing the interference between remote terminals.

[1055] Since channel loading can change relatively dramatically, a fast control mechanism may be used to control the transmit power of the R-SCH (e.g., relative to the reverse pilot channel), as described below.

[1056] A communication between the remote terminal and base station to establish a connection may be achieved as follows. Initially, the remote terminal is in a dormant mode or is monitoring the common channels with the slotted timer active (i.e., the remote terminal is monitoring each slot). At a particular time, the remote terminal desires a data transmission and sends a short message to the base station requesting a reconnection of the link. In response, the base station may send a message specifying the parameters to be used for the communication and the configurations of various channels. This information may be sent via an *Extended Channel Assignment Message* (ECAM), a specially defined message, or some other message. This message may specify the following:

- The MAC_ID for each member of the remote terminal's Active Set or a subset of the Active Set. The MAC_ID is later used for addressing on the forward link.
- Whether the R-DCCH or R-FCH is used on the reverse link.
- For the F-CPANCH, the spreading (e.g., Walsh) codes and Active Set to be used. This may be achieved by (1) sending the spreading codes in the ECAM, or (2) transmitting the spreading codes in a broadcast message, which is received by the remote terminal. The spreading codes of neighbor cells may need to be included. If the same spreading codes can be used in neighboring cells, only a single spreading code may need to be sent.
- For the F-CPCCH, the Active Set, the channel identity, and the bit positions. In an embodiment, the MAC_ID may be hashed to the F-CPCCH bit positions to obviate the need to send the actual bit positions or subchannel ID to the remote terminal. This hashing is a pseudo-random method to map a MAC_ID to a subchannel on the F-CPCCH. Since different simultaneous remote terminals are assigned distinct MAC_IDs, the hashing can be such that these MAC_IDs also map to distinct F-CPCCH subchannels. For example, if there are K possible bit positions and N possible MAC_IDs, then $K = \lfloor N \times ((40503 \times KEY) \bmod 2^{16}) / 2^{16} \rfloor$, where KEY is the number that is fixed in this instance. There

are many other hash functions that can be used and discussions of such can be found in many textbooks dealing with computer algorithms.

[1057] In an embodiment, the message from the base station (e.g., the ECAM) is provided with a specific field, USE_OLD_SERV_CONFIG, used to indicate whether or not the parameters established in the last connection are to be used for the reconnection. This field can be used to obviate the need to send the *Service Connect Message* upon reconnection, which may reduce delay in re-establishing the connection.

[1058] Once the remote terminal has initialized the dedicated channel, it continues, for example, as described in the cdma2000 standard.

[1059] As noted above, better utilization of the reverse link resources may be achieved if the resources can be quickly allocated as needed and if available. In a wireless (and especially mobile) environment, the link conditions continually fluctuate, and long delay in allocating resources may result in inaccurate allocation and/or usage. Thus, in accordance with an aspect of the invention, mechanisms are provided to quickly assign and de-assign supplemental channels.

[1060] FIG. 4 is a diagram illustrating a communication between the remote terminal and base station to assign and de-assign a reverse link supplemental channel (R-SCH), in accordance with an embodiment of the invention. The R-SCH may be quickly assigned and de-assigned as needed. When the remote terminal has packet data to send that requires usage of the R-SCH, it requests the R-SCH by sending to the base station a *Supplemental Channel Request Mini Message* (SCRMM) (step 412). The SCRMM is a 5 msec message that may be sent on the R-DCCH or R-FCH. The base station receives the message and forwards it to the BSC (step 414). The request may or may not be granted. If the request is granted, the base station receives the grant (step 416) and transmits the R-SCH grant using a *Reverse Supplemental Channel Assignment Mini Message* (RSCAMM) (step 418). The RSCAMM is also a 5 msec message that may be sent on the F-FCH or F-DCCH (if allocated to the remote terminal) or on the F-DPCCH (otherwise). Once assigned, the remote terminal may thereafter transmit on the R-SCH (step 420).

[1061] Table 3 lists the fields for a specific format of the RSCAMM. In this embodiment, the RSCAMM includes 8 bits of layer 2 fields (i.e., the MSG_TYPE, ACK_SEQ, MSG_SEQ, and ACK_REQUIREMENT fields), 14 bits of layer 3 fields, and two reserved bits that are also used for padding as described in C.S0004 and C.S0005. The layer 3 (i.e., signaling layer) may be as defined in the cdma2000 standard.

Table 3

Field	Length (Bits)
MSG_TYPE	3
ACK_SEQUENCE	2
MSG_SEQUENCE	2
ACK_REQUIREMENT	1
REV_SCH_ID	1
REV_SCH_DURATION	4
REV_SCH_START_TIME	5
REV_SCH_NUM_BITS_IDX	4
RESERVED	2

[1062] When the remote terminal no longer has data to send on the R-SCH, it sends a *Resource Release Request Mini Message* (RRRMM) to the base station. If there is no additional signaling required between the remote terminal and base station, the base station responds with an *Extended Release Mini Message* (ERMM). The RRRMM and ERMM are also 5 msec messages that may be sent on the same channels used for sending the request and grant, respectively.

[1063] There are many scheduling algorithms that may be used to schedule the reverse link transmissions of remote terminals. These algorithms may tradeoff between rates, capacity, delay, error rates, and fairness (which gives all users some minimal level of services), to indicate some of the main criteria. In addition, the reverse link is subject to the power limitations of the remote terminal. In a single cell environment, the greatest capacity will exist when the smallest number of remote terminals is allowed to transmit with the highest rate that the remote terminal can support -- both in terms of capability and the ability

to provide sufficient power. However, in a multiple cell environment, it may be preferable for remote terminals near the boundary with another cell to transmit at a lower rate. This is because their transmissions cause interference into multiple cells -- not just a single cell. Another aspect that tends to maximize the reverse link capacity is to operate a high rise-over-thermal at the base station, which indicates high loading on the reverse link. It is for this reason that aspects of the invention use scheduling. The scheduling attempts to have a few number of remote terminals simultaneously transmit -- those that do transmit are allowed to transmit at the highest rates that they can support.

[1064] However, a high rise-over-thermal tends to result in less stability as the system is more sensitive to small changes in loading. It is for this reason that fast scheduling and control is important. Fast scheduling is important because the channel conditions change quickly. For instance, fading and shadowing processes may result in a signal that was weakly received at a base station suddenly becoming strong at the base station. For voice or certain data activity, the remote terminal autonomously changes the transmission rate While scheduling may be able to take some of this into account, scheduling may not be able to react sufficiently fast enough. For this reason, aspects of the invention provide fast power control techniques, which are described in further detail below.

[1065] An aspect of the invention provides a reliable acknowledgment/negative acknowledgment scheme to facilitate efficient and reliable data transmission. As described above, acknowledgments (Ack) and negative acknowledgments (Nak) are sent by the base station for data transmission on the R-SCH. The Ack/Nak can be sent using the F-CPANCH.

[1066] Table 4 shows a specific format for an Ack/Nak message. In this specific embodiment, the Ack/Nak message includes 4 bits that are assigned to four reverse link channels - the R-FCH, R-DCCH, R-SCH1, and R-SCH2. In an embodiment, an acknowledgment is represented by a bit value of zero ("0") and a negative acknowledgment is represented by a bit value of one ("1"). Other Ack/Nak message formats may also be used and are within the scope of the invention.

Table 4

Description	All Channels Used Number_Type (binary)	R-FCH, R-DCCH, and R-SCH1 Used Number_Type (binary)	R-FCH and R-DCCH Used Number_Type (binary)
ACK_R-FCH	xxx0	xxx0	xx00
NAK_R-FCH	xxx1	xxx1	xx11
ACK_R-DCCH	xx0x	xx0x	-
NAK_R-DCCH	xx1x	xx1x	-
ACK_R-SCH1	x0xx	00xx	00xx
NAK_R-SCH1	x1xx	11xx	11xx
ACK_R-SCH2	0xxx	-	-
NAK_R-SCH2	1xxx	-	-

[1067] In an embodiment, the Ack/Nak message is sent block coded but a CRC is not used to check for errors. This keeps the Ack/Nak message short and further allows the message to be sent with a small amount of energy. However, no coding may also be used for the Ack/Nak message, or a CRC may be attached to the message, and these variations are within the scope of the invention. In an embodiment, the base station sends an Ack/Nak message corresponding to each frame in which the remote terminal has been given permission to transmit on the R-SCH, and does not send Ack/Nak messages during frames that the remote terminal is not given permission to transmit.

[1068] During a packet data transmission, the remote terminal monitors the F-CPANCH for Ack/Nak messages that indicate the results of the transmission. The Ack/Nak messages may be transmitted from any number of base stations in the remote terminal's Active Set (e.g., from one or all base stations in the Active Set). The remote terminal can perform different actions depending on the received Ack/Nak messages. Some of these actions are described below.

[1069] If an Ack is received by the remote terminal, the data frame corresponding to the Ack may be removed from the remote terminal's physical layer transmit buffer (e.g., data source 210 in FIG. 2) since the data frame was correctly received by the base station.

[1070] If a Nak is received by the remote terminal, the data frame corresponding to the Nak may be retransmitted by the remote terminal if it is still in the physical layer transmit buffer. In an embodiment, there is a one-to-one correspondence between a forward link Ack/Nak message and a transmitted reverse link data frame. The remote terminal is thus able to identify the sequence number of the data frame not received correctly by the base station (i.e., the erased frame) based on the frame in which the Nak was received. If this data frame has not been discarded by the remote terminal, it may be retransmitted at the next available time interval, which is typically the next frame.

[1071] If neither an Ack nor a Nak was received, there are several next possible actions for the remote terminal. In one possible action, the data frame is maintained in the physical layer transmit buffer and retransmitted. If the retransmitted data frame is then correctly received at the base station, then the base station transmits an Ack. Upon correct receipt of this Ack, the remote terminal discards the data frame. This would be the best approach if the base station did not receive the reverse link transmission.

[1072] Another possible action is for the remote terminal to discard the data frame if neither an Ack nor a Nak was received. This would be the best alternative if the base station had received the frame but the Ack transmission was not received by the remote terminal. However, the remote terminal does not know the scenario that occurred and a policy needs to be chosen. One policy would be to ascertain the likelihood of the two events happening and performing the action that maximizes the system throughput.

[1073] In an embodiment, each Ack/Nak message is retransmitted a particular time later (e.g., at the next frame) to improve reliability of the Ack/Nak. Thus, if neither an Ack nor a Nak was received, the remote terminal combines the retransmitted Ack/Nak with the original Ack/Nak. Then, the remote terminal can proceed as described above. And if the combined Ack/Nak still does not result in a valid Ack or Nak, the remote terminal may discard the data frame and continue to transmit the next data frame in the sequence. The second transmission of the Ack/Nak may be at the same or lower power level relative to that of the first transmission.

[1074] If the base station did not actually receive the data frame after retransmissions, then a higher signaling layer at the base station may generate a message (e.g., an RLP NAK), which may result in the retransmission of the entire sequence of data frames that includes the erased frame.

[1075] FIG. 5A is a diagram illustrating a data transmission on the reverse link (e.g., the R-SCH) and an Ack/Nak transmission on the forward link. The remote terminal initially transmits a data frame, in frame *k*, on the reverse link (step 512). The base station receives and processes the data frame, and provides the demodulated frame to the BSC (step 514). If the remote terminal is in soft handoff, the BSC may also receive demodulated frames for the remote terminal from other base stations.

[1076] Based on the received demodulated frames, the BSC generates an Ack or a Nak for the data frame. The BSC then sends the Ack/Nak to the base station(s) (step 516), which then transmit the Ack/Nak to the remote terminal during frame *k*+1 (step 518). The Ack/Nak may be transmitted from one base station (e.g., the best base station) or from a number base stations in the remote terminal's Active Set. The remote terminal receives the Ack/Nak during frame *k*+1. If a Nak is received, the remote terminal retransmits the erased frame at the next available transmission time, which in this example is frame *k*+2 (step 520). Otherwise, the remote terminal transmits the next data frame in the sequence.

[1077] FIG. 5B is a diagram illustrating a data transmission on the reverse link and a second transmission of the Ack/Nak message. The remote terminal initially transmits a data frame, in frame *k*, on the reverse link (step 532). The base station receives and processes the data frame, and provides the demodulated frame to the BSC (step 534). Again, for soft handoff, the BSC may receive other demodulated frames for the remote terminal from other base stations.

[1078] Based on the received demodulated frames, the BSC generates an Ack or a Nak for the frame. The BSC then sends the Ack/Nak to the base station(s) (step 536), which then transmit the Ack/Nak to the remote terminal during frame *k*+1 (step 538). In this example, the remote terminal does not receive the Ack/Nak transmitted during frame *k*+1. However, the Ack/Nak for

the data frame transmitted in frame *k* is transmitted a second time during frame *k*+2, and is received by the remote terminal (step 540). If a Nak is received, the remote terminal retransmits the erased frame at the next available transmission time, which in this example is frame *k*+3 (step 542). Otherwise, the remote terminal transmits the next data frame in the sequence. As shown in FIG. 5B, the second transmission of the Ack/Nak improves the reliability of the feedback, and can result in improved performance for the reverse link.

[1079] In an alternative embodiment, the data frames are not sent back to the BSC from the base station, and the Ack/Nak is generated from the base station.

[1080] FIG. 6A is a diagram illustrating an acknowledgment sequencing with short acknowledgment delay. The remote terminal initially transmits a data frame with a sequence number of zero, in frame *k*, on the reverse link (step 612). For this example, the data frame is received in error at the base station, which then sends a Nak during frame *k*+1 (step 614). The remote terminal also monitors the F-CPANCH for an Ack/Nak message for each data frame transmitted on the reverse link. The remote terminal continues to transmit a data frame with a sequence number of one in frame *k*+1 (step 616).

[1081] Upon receiving the Nak in frame *k*+1, the remote terminal retransmits the erased frame with the sequence number of zero, in frame *k*+2 (step 618). The data frame transmitted in frame *k*+1 was received correctly, as indicated by an Ack received during frame *k*+2, and the remote terminal transmits a data frame with a sequence number of two in frame *k*+3 (step 620). Similarly, the data frame transmitted in frame *k*+2 was received correctly, as indicated by an Ack received during frame *k*+3, and the remote terminal transmits a data frame with a sequence number of three in frame *k*+4 (step 622). In frame k+5, the remote terminal transmits a data frame with a sequence number of zero for a new packet (step 624).

[1082] FIG. 6B is a diagram illustrating an acknowledgment sequencing with long acknowledgment delay such as when the remote terminal demodulates the Ack/Nak transmission based upon the retransmission of the Ack/Nak as described above. The remote terminal initially transmits a data frame with a sequence number of zero, in frame *k*, on the reverse link (step 632). The data

frame is received in error at the base station, which then sends a Nak (step 634). For this example, because of the longer processing delay, the Nak for frame k is transmitted during frame k+2. The remote terminal continues to transmit a data frame with a sequence number of one in frame k+1 (step 636) and a data frame with a sequence number of two in frame k+2 (step 638).

[1083] For this example, the remote terminal receives the Nak in frame k+2, but is not able to retransmit the erased frame at the next transmission interval. Instead, the remote terminal transmits a data frame with a sequence number of three in frame k+3 (step 640). At frame k+4, the remote terminal retransmits the erased frame with the sequence number of zero (step 642) since this frame is still in the physical layer buffer. Alternatively, the retransmission may be in frame k+3. And since the data frame transmitted in frame k+1 was received correctly, as indicated by an Ack received during frame k+3, and the remote terminal transmits a data frame with a sequence number of zero for a new packet (step 644).

[1084] As shown in FIG. 6B, the erased frame may be retransmitted at any time as long as it is still available in the buffer and there is no ambiguity as to which higher layer packet the data frame belongs to. The longer delay for the retransmission may be due to any number of reasons such as (1) longer delay to process and transmit the Nak, (2) non-detection of the first transmission of the Nak, (3) longer delay to retransmit the erased frame, and others.

[1085] An efficient and reliable Ack/Nak scheme can improve the utilization of the reverse link. A reliable Ack/Nak scheme may also allow data frames to be transmitted at lower transmit power. For example, without retransmission, a data frame needs to be transmitted at a higher power level (P_1) required to achieve one percent frame error rate (1% FER). If retransmission is used and is reliable, a data frame may be transmitted at a lower power level (P_2) required to achieve 10% FER. The 10% erased frames may be retransmitted to achieve an overall 1% FER for the transmission. Typically, $1.1 \cdot P_2 < P_1$, and less transmit power is used for a transmission using the retransmission scheme. Moreover, retransmission provides time diversity, which may improve performance. The retransmitted frame may also be combined with the first transmission of the frame at the base station, and the combined power from the two transmissions

may also improve performance. The recombining may allow an erased frame to be retransmitted at a lower power level.

[1086] An aspect of the invention provides various power control schemes for the reverse link. In an embodiment, reverse link power control is supported for the R-FCH, R-SCH, and R-DCCH. This can be achieved via a (e.g., 800 bps) power control channel, which may be partitioned into a number of power control subchannels. For example, a 100 bps power control subchannel may be defined and used for the R-SCH. If the remote terminal has not been allocated a F-FCH or F-DCCH, then the F-CPCCH may be used to send power control bits to the remote terminal.

[1087] In one implementation, the (e.g., 800 bps) power control channel is used to adjust the transmit power of the reverse link pilot. The transmit power of the other channels (e.g., the R-FCH) is set relative to that of the pilot (i.e., by a particular delta). Thus, the transmit power for all reverse link channels may be adjusted along with the pilot. The delta for each non-pilot channel may be adjusted by signaling. This implementation does not provide flexibility to quickly adjust the transmit power of different channels.

[1088] In one embodiment, the forward common power control channel (F-CPCCH) may be used to form one or more power control subchannels that may then be used for various purposes. Each power control subchannel may be defined using a number of available bits in the F-CPCCH (e.g., the m^{th} bit in each frame). For example, some of the available bits in the F-CPCCH may be allocated for a 100 bps power control subchannel for the R-SCH. This R-SCH power control subchannel may be assigned to the remote terminal during channel assignment. The R-SCH power control subchannel may then be used to (more quickly) adjust the transmit power of the designated R-SCH, e.g., relative to that of the pilot channel. For a remote terminal in soft handoff, the R-SCH power control may be based on the OR-of-the-downs rule, which decreases the transmit power if any base station in the remote terminal's Active Set directs a decrease. Since the power control is maintained at the base station, this permits the base station to adjust the transmitted power with minimal amount of delay and thus adjust the loading on the channel.

[1089] The R-SCH power control subchannel may be used in various manners to control the transmission on the R-SCH. In an embodiment, the R-SCH power control subchannel may be used to direct the remote terminal to adjust the transmit power on the R-SCH by a particular amount (e.g., 1 dB, 2 dB, or some other value). In another embodiment, the subchannel may be used to direct the remote terminal to reduce or increase transmit power by a large step (e.g., 3 dB, or possibly more). In both embodiments, the adjustment in transmit power may be relative to the pilot transmit power. In another embodiment, the subchannel may be directed to adjust the data rate allocated to the remote terminal (e.g., to the next higher or lower rate). In yet another embodiment, the subchannel may be used to direct the remote terminal to temporarily stop transmission. And in yet another embodiment, the remote terminal may apply different processing (e.g., different interleaving interval, different coding, and so on) based on the power control command. The R-SCH power control subchannel may also be partitioned into a number of "sub-subchannels", each of which may be used in any of the manners described above. The sub-subchannels may have the same or different bit rates. The remote terminal may apply the power control immediately upon receiving the command, or may apply the command at the next frame boundary.

[1090] The ability to reduce the R-SCH transmit power by a large amount (or down to zero) without terminating the communication session is especially advantageous to achieve better utilization of the reverse link. Temporary reduction or suspension of a packet data transmission can typically be tolerated by the remote terminal. These power control schemes can be advantageously used to reduce interference from a high rate remote terminal.

[1091] Power control of the R-SCH may be achieved in various manners. In one embodiment, a base station monitors the received power from the remote terminals with a power meter. The base station may even be able to determine the amount of power received from each channel (e.g., the R-FCH, R-DCCH, R-SCH, and so on). The base station is also able to determine the interference, some of which may be contributed by remote terminals not being served by this base station. Based on the collected information, the base station may adjust the transmit power of some or all remote terminals based on various factors.

For example, the power control may be based on the remote terminals' category of service, recent performance, recent throughput, and so on. The power control is performed in a manner to achieve the desired system goals.

[1092] Power control may be implemented in various manners. Example implementations are described in U.S Patent No. 5,485,486, entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM," issued January 16, 1996, U.S Patent No. 5,822,318, entitled "METHOD AND APPARATUS FOR CONTROLLING POWER IN A VARIABLE RATE COMMUNICATION SYSTEM," issued October 13, 1998, and U.S Patent No. 6,137,840, entitled "METHOD AND APPARATUS FOR PERFORMING FAST POWER CONTROL IN A MOBILE COMMUNICATION SYSTEM," issued October 24, 2000, all assigned to the assignee of the present application and incorporated herein by reference.

[1093] In a typical method of power control that is used to control the level of the R-PICH channel, the base station measures the level of the R-PICH, compares it to a threshold, and then determines whether to increase or decrease the power of the remote terminal. The base station transmits a bit to the remote terminal instructing it to increase or decrease its output power. If the bit is received in error, the remote terminal will transmit at the incorrect power. During the next measurement of the R-PICH level received by the base station, the base station will determine that the received level is not at the desired level and send a bit to the remote terminal to change its transmit power. Thus, bit errors do not accumulate and the loop controlling the remote terminal's transmit power will stabilize to the correct value.

[1094] Errors in the bits sent to the remote terminal to control the traffic-to-pilot ratio for congestion power control can cause the traffic-to-pilot ratio to be other than that desired. However, the base station typically monitors the level of the R-PICH for reverse power control or for channel estimation. The base station can also monitor the level of the received R-SCH. By taking the ratio of the R-SCH level to the R-PICH level, the base station can estimate the traffic-to-pilot ratio in use by the remote terminal. If the traffic-to-pilot ratio is not that which is desired, then the base station can set the bit that controls the traffic-to-

pilot ratio to correct for the discrepancy. Thus, there is a self-correction for bit errors.

[1095] Once a remote terminal has received a grant for the R-SCH, the remote terminal typically transmits at the granted rate (or below in case it doesn't have enough data to send or does not have sufficient power) for the duration of the grant. The channel load from other remote terminals can vary quite quickly as a result of fading and the like. As such, it may be difficult for the base station to estimate the loading precisely in advance.

[1096] In an embodiment, a "congestion" power control subchannel may be provided to control a group of remote terminals in the same manner. In this case, instead of a single remote terminal monitoring the power control subchannel to control the R-SCH, a group of remote terminals monitor the control subchannel. This power control subchannel can be at 100 bps or at any other transmission rate. In one embodiment, the congestion control subchannel is implemented with the power control subchannel used for the R-SCH. In another embodiment, the congestion control subchannel is implemented as a "sub-subchannel" of the R-SCH power control subchannel. In yet another embodiment, the congestion control subchannel is implemented as a subchannel different from the R-SCH power control subchannel. Other implementations of the congestion control subchannel may also be contemplated and are within the scope of the invention.

[1097] The remote terminals in the group may have the same category service (e.g., remote terminals having low priority available bit rate services) and may be assigned to a single power control bit per base station. This group control based on a single power control stream performs similar to that directed to a single remote terminal to provide for congestion control on the reverse link. In case of capacity overload, the base station may direct this group of remote terminals to reduce their transmit power or their data rates, or to temporarily stop transmitting, based on a single control command. The reduction in the R-SCH transmit power in response to the congestion control command may be a large downward step relative to the transmit power of the pilot channel.

[1098] The advantage of a power control stream going to a group of remote terminals instead of a single remote terminal is that less overhead power is

required on the forward link to support the power control stream. It should be noted that the transmit power of a bit in the power control stream can be equal to the power of the normal power control stream used to the control the pilot channel for the remote terminal that requires the most power. That is, the base station can determine the remote terminal in the group that requires the greatest power in its normal power control stream and then use this power to transmit the power control bit used for congestion control.

[1099] FIG. 7 is a flow diagram that illustrates a variable rate data transmission on the R-SCH with fast congestion control, in accordance with an embodiment of the invention. During the transmission on the R-SCH, the remote terminal transmits in accordance with the data rate granted in the *Reverse Supplemental Channel Assignment Mini Message* (RSAMM). If variable rate operation is permitted on the R-SCH, the remote terminal may transmit at any one of a number of permitted data rates.

[1100] If the remote terminal's R-SCH has been assigned to a congestion control subchannel, then, in an embodiment, the remote terminal adjusts the traffic-to-pilot ratio based upon the bits received in the congestion control subchannel. If variable rate operation is permitted on the R-SCH, the remote terminal checks the current traffic-to-pilot ratio. If it is below the level for a lower data rate, then the remote terminal reduces its transmission rate to the lower rate. If it is equal to or above the level for a higher data rate, then the remote terminal increases its transmission rate to the higher rate if it has sufficient data to send.

[1101] Prior to the start of each frame, the remote terminal determines the rate to use for transmitting the next data frame. Initially, the remote terminal determines whether the R-SCH traffic-to-pilot ratio is below that for the next lower rate plus a margin Δ_{low}, at step 712. If the answer is yes, a determination is made whether the service configuration allows for a reduction in the data rate, at step 714. And if the answer is also yes, the data rate is decreased, and the same traffic-to-pilot ratio is used, at step 716. And if the service configuration does not allow for a rate reduction, a particular embodiment would permit the remote terminal to temporarily stop transmitting.

[1102] Back at step 712, if the R-SCH traffic-to-pilot ratio is not above that for the next lower data rate plus the margin Δ_{low}, a determination is next made as to whether the R-SCH traffic-to-pilot ratio is greater than that for the next higher data rate minus a margin Δ_{high}, at step 718. If the answer is yes, a determination is made whether the service configuration allows for an increase in the data rate, at step 720. And if the answer is also yes, the transmission rate is increased, and the same traffic-to-pilot ratio is used, at step 722. And if the service configuration does not allow for a rate increase, the remote terminal transmits at the current rate.

[1103] FIG. 8 is a diagram illustrating improvement that may be possible with fast control of the R-SCH. On the left frame, without any fast control of the R-SCH, the rise-over-thermal at the base station varies more widely, exceeding the desired rise-over-thermal level by a larger amount in some instances (which may result in performance degradation for the data transmissions from the remote terminals), and falling under desired rise-over-thermal level by a larger amount in some other instances (resulting in under-utilization of the reverse link resources). In contrast, on the right frame, with fast control of the R-SCH, the rise-over-thermal at the base station is maintained more closely to the desired rise-over-thermal level, which results in improved reverse link utilization and performance.

[1104] In an embodiment, a base station may schedule more than one remote terminal (via SCAM or ESCAM) to transmit, in response to receiving multiple requests (via SCRM or SCRMM) from different remote terminals. The granted remote terminals may thereafter transmit on the R-SCH. If overloading is detected at the base station, a "fast reduce" bit stream may be used to turn off (i.e., disable) a set of remote terminals (e.g., all except one remote terminal). Alternatively, the fast reduce bit stream may be used to reduce the data rates of the remote terminals (e.g., by half). Temporarily disabling or reducing the data rates on the R-SCH for a number of remote terminals may be used for congestion control, as described in further detail below. The fast reduce capability may also be advantageously used to shorten the scheduling delay.

[1105] When the remote terminals are not in soft handoff with other base stations, the decision on which remote terminal is the most advantaged (efficient) to use the reverse link capacity may be made at the BTS. The most efficient remote terminal may then be allowed to transmit while the others are temporarily disabled. If the remote terminal signals the end of its available data, or possibly when some other remote terminal becomes more efficient, the active remote terminal can quickly be changed. These schemes may increase the throughput of the reverse link.

[1106] In contrast, for a usual set up in a cdma2000 system, a R-SCH transmission can only start or stop via layer 3 messaging, which may take several frames from composing to decoding at the remote terminal to get across. This longer delay causes a scheduler (e.g., at the base station or BSC) to work with (1) less reliable, longer-term predictions about the efficiency of the remote terminal's channel condition (e.g., the reverse link target pilot Ec/(No+Io) or set point), or (2) gaps in the reverse link utilization when a remote terminal notifies the base station of the end of its data (a common occurrence since a remote terminal often claims it has a large amount of data to send to the base station when requesting the R-SCH).

[1107] Referring back to FIG. 2, the elements of remote terminal 106 and base station 104 may be designed to implement various aspects of the invention, as described above. The elements of the remote terminal or base station may be implemented with a digital signal processor (DSP), an application specific integrated circuit (ASIC), a processor, a microprocessor, a controller, a microcontroller, a field programmable gate array (FPGA), a programmable logic device, other electronic units, or any combination thereof. Some of the functions and processing described herein may also be implemented with software executed on a processor, such as controller 230 or 270.

[1108] Headings are used herein to serve as general indications of the materials being disclosed, and are not intended to be construed as to scope.

[1109] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those

skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[1110] **WHAT IS CLAIMED IS:**

CLAIMS

1. A channel structure capable of supporting data transmission on a reverse link of a wireless communication system, comprising:

a reverse fundamental channel configurable to transmit data and signaling on the reverse link;

a reverse supplemental channel assignable and configurable to transmitted packet data on the reverse link;

a reverse control channel configurable to transmit signaling on the reverse link; and

a forward power control channel configurable to transmit first and second power control streams for the reverse link for a particular remote terminal, wherein

the first power control stream is used to control the transmit power of the reverse supplemental channel in combination with at least one other reverse link channel, and

the second power control stream is used to control a transmit characteristic of the reverse supplemental channel.

2. The channel structure of claim 1, wherein the second power control stream is used to control the transmit power of the reverse supplemental channel relative to that of a designated reverse link channel.

3. The channel structure of claim 1, wherein the second power control stream is used to control the data rate of the reverse supplemental channel.

4. The channel structure of claim 1, further comprising:

a forward acknowledgment channel configurable to transmit, on the forward link, signaling indicative of received status of the packet data transmission on the reverse link.

5. The channel structure of claim 4, wherein the forward acknowledgment channel is configurable to transmit an acknowledgment or a negative acknowledgment for each transmitted data frame on the reverse supplemental channel.

6. The channel structure of claim 5, wherein the acknowledgment or negative acknowledgment for each transmitted data frame is transmitted a plurality of times on the forward acknowledgment channel.

7. The channel structure of claim 1, wherein the reverse control channel is configurable to transmit signaling used to assign and de-assign the reverse supplemental channel.

8. The channel structure of claim 1, further comprising:

a reverse rate indicator channel configurable to transmit on the reverse link information related to a packet data transmission on the reverse link.

9. A channel structure capable of supporting data transmission on a reverse link of a wireless communication system, comprising:

a reverse fundamental channel configurable to transmit data and signaling on the reverse link;

a reverse supplemental channel assignable and configurable to transmitted packet data on the reverse link;

a reverse control channel configurable to transmit signaling on the reverse link; and

a forward power control channel configurable to transmit first and second power control streams for the reverse link for a particular remote terminal, wherein

the first power control stream is used to control the transmit power of the reverse supplemental channel in combination with at least one other reverse link channel, and

the second power control stream is configured to control a transmit characteristic of a group of remote terminals.

10. The channel structure of claim 9, wherein the second power control stream is used to similarly control the transmit power or data rate of the group of remote terminals.

11. The channel structure of claim 9, wherein the second power control stream is used to enable and disable transmissions on reverse supplemental channels assigned to the group of remote terminals.

12. A method for transmitting data on a reverse link of a wireless communication system, comprising:

transmitting a frame of data on the reverse link via a data channel;

temporarily retaining the data frame in a buffer;

monitoring for a message on a forward link indicating a received status of the transmitted data frame; and

processing the data frame based on the received message.

13. The method of claim 12, wherein the processing includes;

retransmitting the data frame if the message indicates that the transmitted data frame was incorrectly received.

14. The method of claim 12, wherein the processing includes;

discarding the data frame from the buffer if the message indicates that the transmitted data frame was correctly received.

15. The method of claim 12, wherein the processing includes;

retaining the data frame in the buffer if the message is not properly detected.

16. The method of claim 12, further comprising:

monitoring for a second transmission of the message;

wherein the processing of the data frame is based on one or more received messages for the data frame.

17. The method of claim 16, further comprising:
combining the received messages for the data frame to provide a more reliable message.

18. The method of claim 12, further comprising:
identifying the transmitted data frame with a sequence number.

19. The method of claim 18, further comprising:
transmitting the sequence number of the transmitted data frame via a signaling channel.

20. The method of claim 12, further comprising:
identifying the transmitted data frame as either a first transmission or a retransmission.

21. A method for transmitting data on a reverse link of a wireless communication system, comprising:
transmitting a frame of data on the reverse link via a data channel;
temporarily retaining the data frame in a buffer;
monitoring for a message on a forward link indicating a received status of the transmitted data frame;
retransmitting the data frame if the message indicates that the transmitted data frame was incorrectly received;
discarding the data frame from the buffer if the message indicates that the transmitted data frame was correctly received; and
retaining the data frame in the buffer if the message is not properly detected.

22. A method for controlling transmit power of a supplemental channel in a reverse link of a wireless communication system, comprising:

receiving a first power control stream for controlling the transmit power of the supplemental channel in combination with at least one other reverse link channel;

receiving a second power control stream for controlling a transmit characteristic of the supplemental channel; and

adjusting the transmit power and characteristic of the supplemental channel based on the first and second power control streams.

23. The method of claim 22, wherein the second power control stream controls the transmit power of the supplemental channel relative to that of a designated reverse link channel.

24. The method of claim 22, wherein the second power control stream controls a data rate of the supplemental channel.

25. The method of claim 22, wherein the second power control stream enables and disables transmission on the supplemental channel.

26. The method of claim 22, wherein the transmit power of the supplemental channel is adjusted by a larger step in response to the second power control stream than for the first power control stream.

27. The method of claim 22, wherein the second power control stream is assigned to a plurality of remote terminals.

28. The method of claim 28, wherein supplemental channels for the plurality of remote terminals are controlled in similar manner by the second power control stream.

29. A remote terminal in a wireless communication system, comprising:

a transmit data processor configurable to process and transmit

data and signaling on a reverse fundamental channel,

packet data on an assigned reverse supplemental channel,

signaling on a reverse control channel, and

information related to a packet data transmission on a reverse indicator channel;

a receive data processor configurable to receive a plurality of power control streams on a forward power control channel; and

a controller operatively coupled to the transmit and receive data processors and configured to control one or more transmit characteristics of the reverse supplemental channel based on the plurality of power control streams.

30. The remote terminal of claim 29, wherein the receive data processor is further configurable to receive, on a forward acknowledgment channel, signaling indicative of received status of a packet data transmission on the reverse supplemental channel.

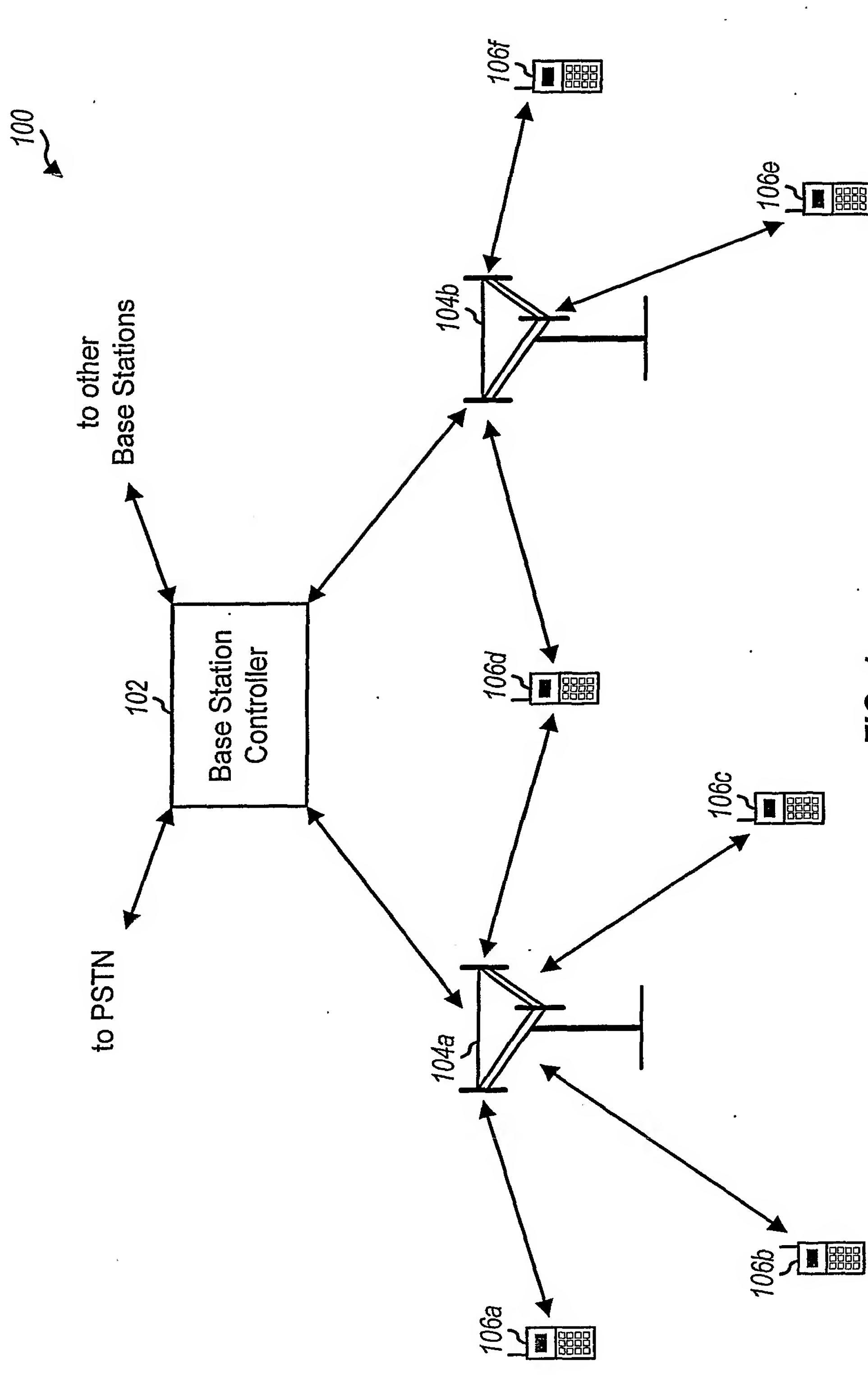
100
to other
Base Stations
to PSTN
102
Base Station
Controller
104a
104b
106a
106b
106c
106d
106e
106f

FIG. 1

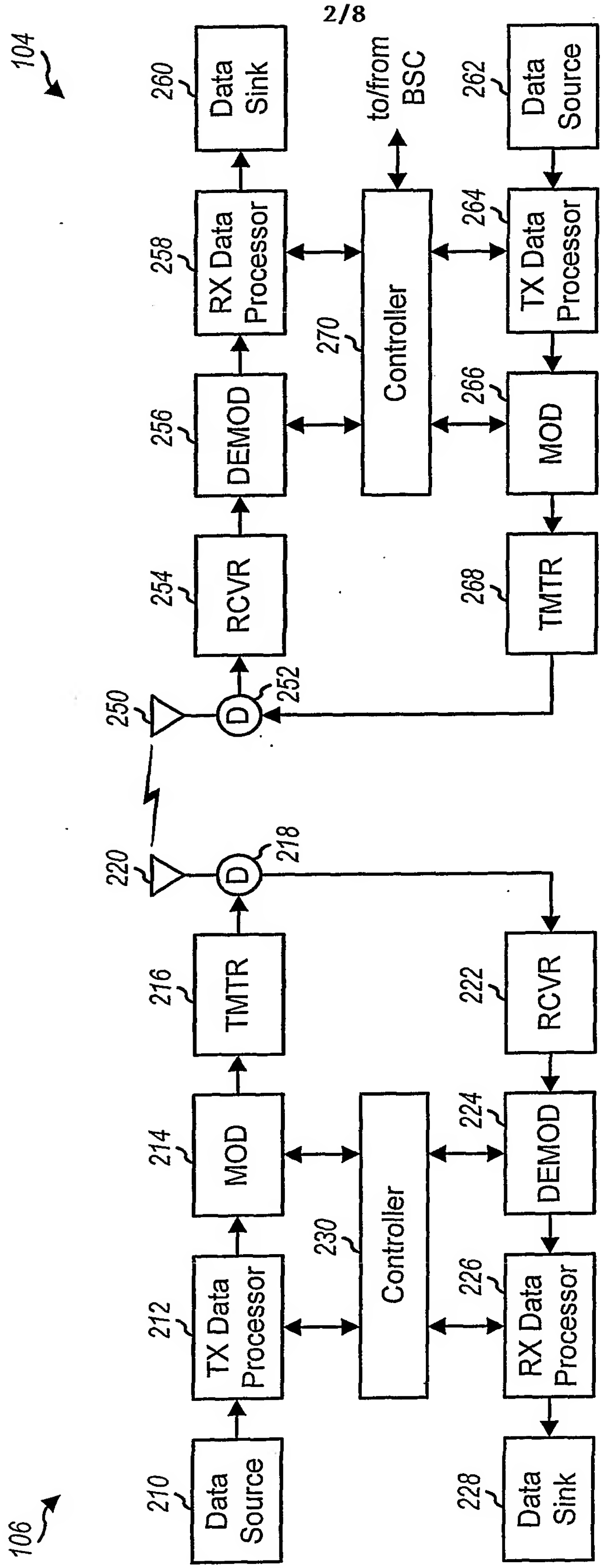
104
260
Data Sink
258
RX Data Processor
256
DEMOD
254
RCVR
250
252
D
to/from BSC
270
Controller
262
Data Source
264
TX Data Processor
266
MOD
268
TMTR
220
218
D
216
TMTR
214
MOD
212
TX Data Processor
210
Data Source
230
Controller
222
RCVR
224
DEMOD
226
RX Data Processor
228
Data Sink
106

FIG. 2

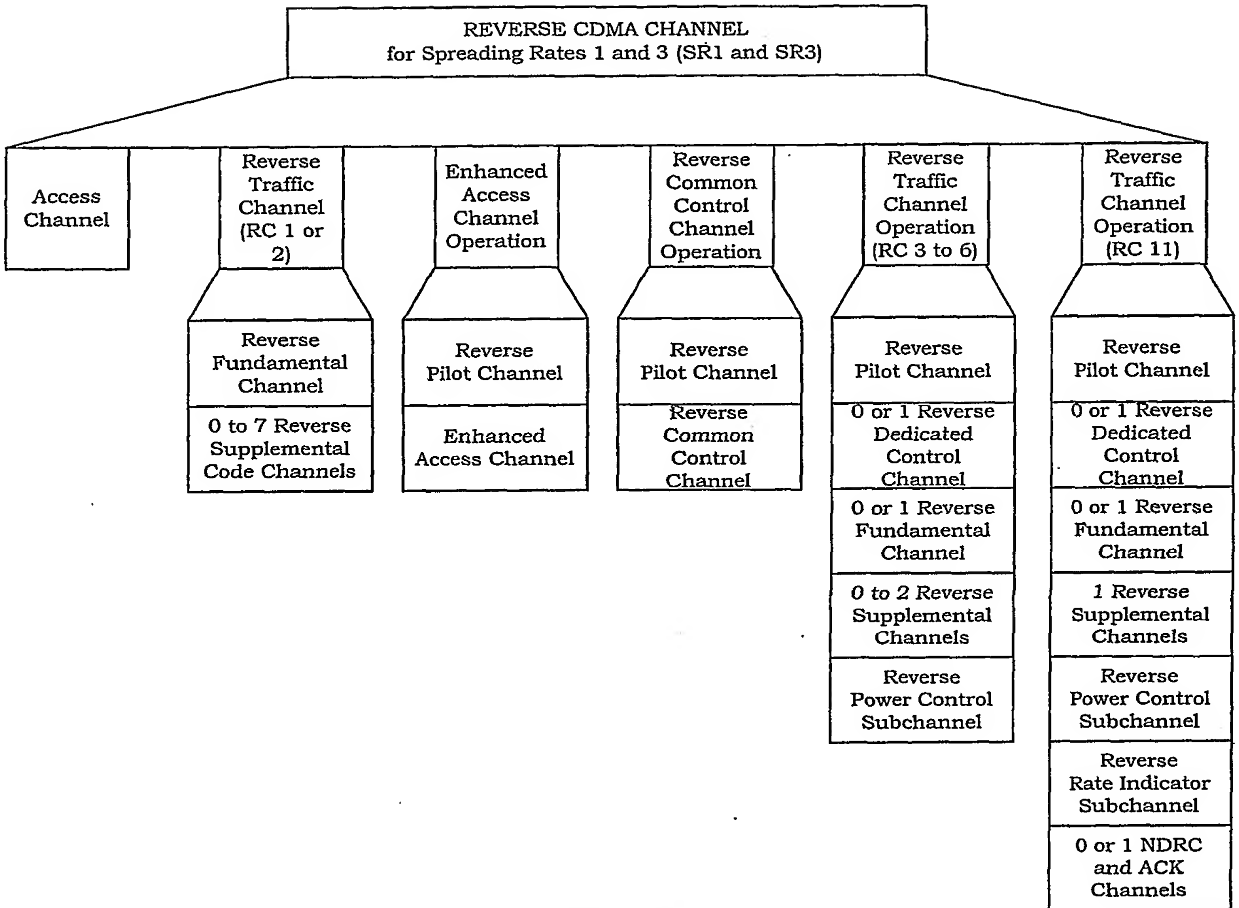
REVERSE CDMA CHANNEL
for Spreading Rates 1 and 3 (SR1 and SR3)
Access Channel
Reverse Traffic Channel (RC 1 or 2)
Enhanced Access Channel Operation
Reverse Common Control Channel Operation
Reverse Traffic Channel Operation (RC 3 to 6)
Reverse Traffic Channel Operation (RC 11)
Reverse Fundamental Channel
0 to 7 Reverse Supplemental Code Channels
Reverse Pilot Channel
Enhanced Access Channel
Reverse Pilot Channel
Reverse Common Control Channel
Reverse Pilot Channel
0 or 1 Reverse Dedicated Control Channel
0 or 1 Reverse Fundamental Channel
0 to 2 Reverse Supplemental Channels
Reverse Power Control Subchannel
Reverse Pilot Channel
0 or 1 Reverse Dedicated Control Channel
0 or 1 Reverse Fundamental Channel
1 Reverse Supplemental Channels
Reverse Power Control Subchannel
Reverse Rate Indicator Subchannel
0 or 1 NDRC and ACK Channels

FIG. 3A

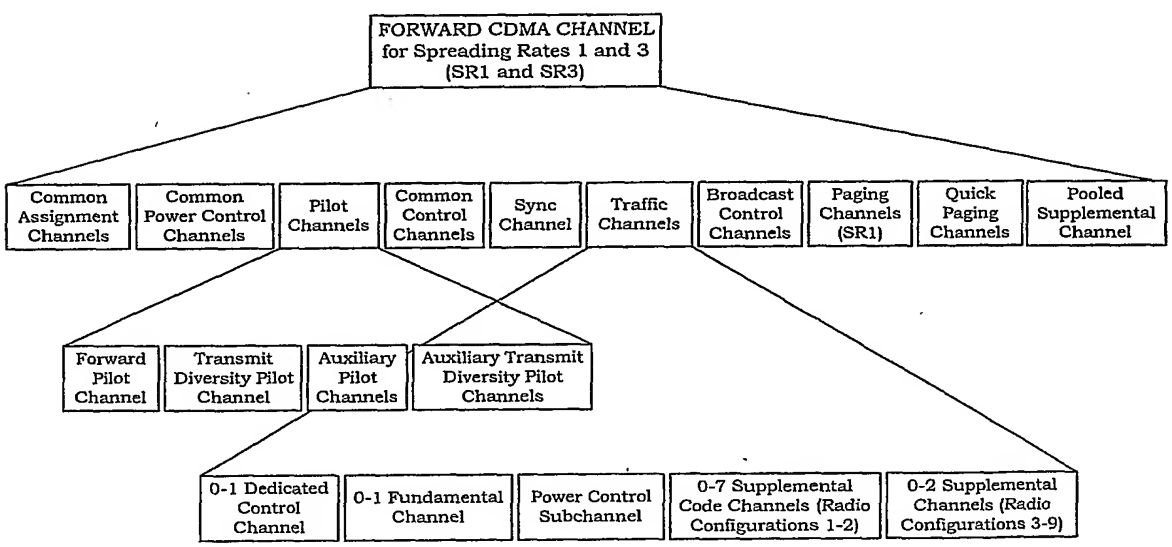
FORWARD CDMA CHANNEL
for Spreading Rates 1 and 3
(SR1 and SR3)
Common Assignment Channels
Common Power Control Channels
Pilot Channels
Common Control Channels
Sync Channel
Traffic Channels
Broadcast Control Channels
Paging Channels (SR1)
Quick Paging Channels
Pooled Supplemental Channel
Forward Pilot Channel
Transmit Diversity Pilot Channel
Auxiliary Pilot Channels
Auxiliary Transmit Diversity Pilot Channels
0-1 Dedicated Control Channel
0-1 Fundamental Channel
Power Control Subchannel
0-7 Supplemental Code Channels (Radio Configurations 1-2)
0-2 Supplemental Channels (Radio Configurations 3-9)

FIG. 3B

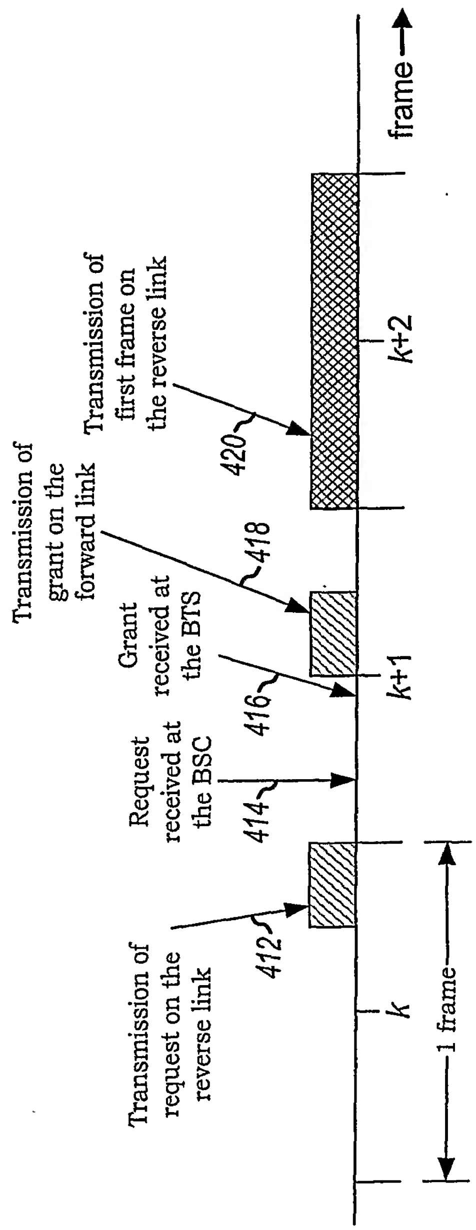
Transmission of request on the reverse link
412
Request received at the BSC
414
Grant received at the BTS
416
Transmission of grant on the forward link
418
Transmission of first frame on the reverse link
420
k
k+1
k+2
1 frame
frame

FIG. 4

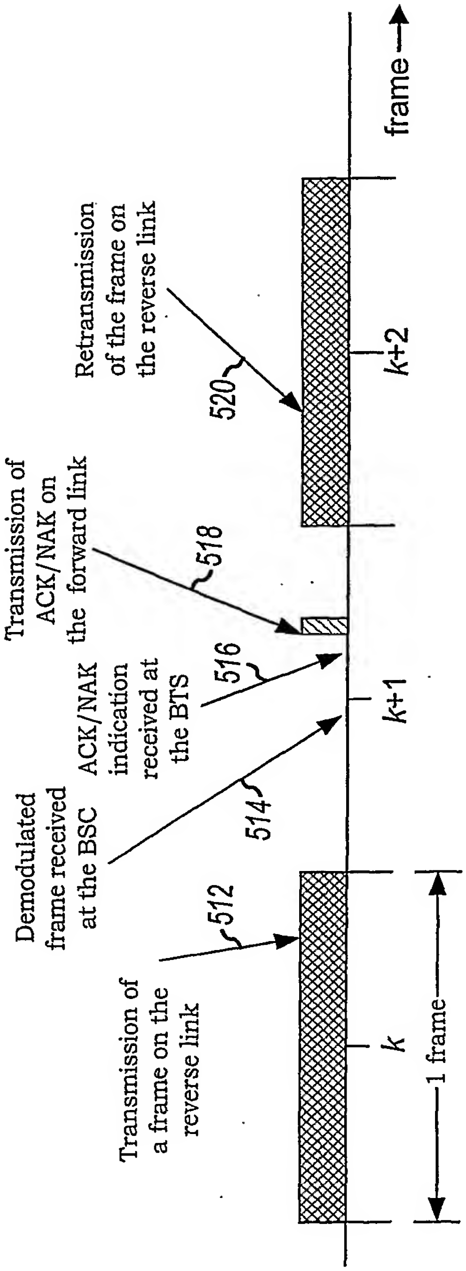
Transmission of a frame on the reverse link
512
Demodulated frame received at the BSC
514
ACK/NAK indication received at the BTS
516
Transmission of ACK/NAK on the forward link
518
Retransmission of the frame on the reverse link
520
k
k+1
k+2
1 frame
frame

FIG. 5A

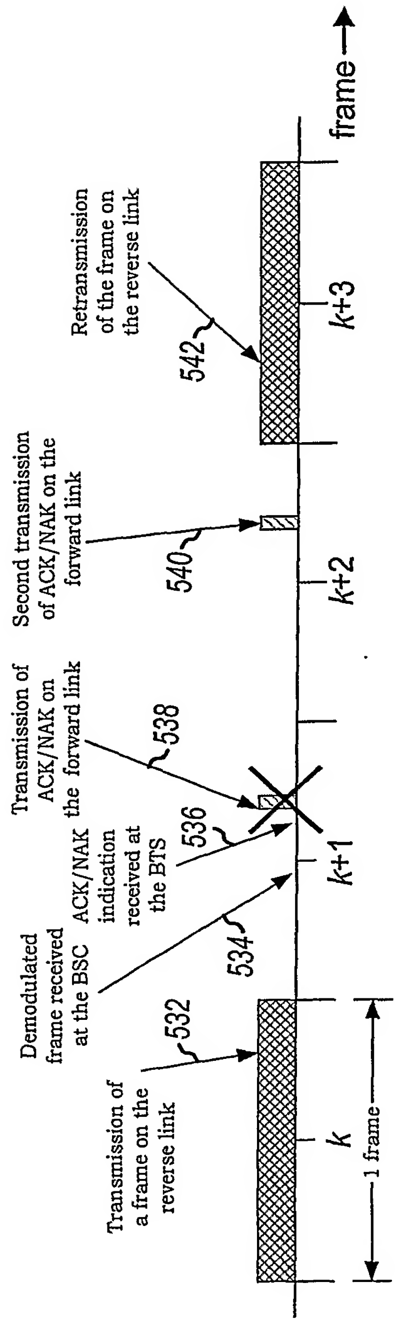
Transmission of a frame on the reverse link
532
Demodulated frame received at the BSC
534
ACK/NAK indication received at the BTS
536
Transmission of ACK/NAK on the forward link
538
Second transmission of ACK/NAK on the forward link
540
Retransmission of the frame on the reverse link
542
k
k+1
k+2
k+3
1 frame
frame

FIG. 5B

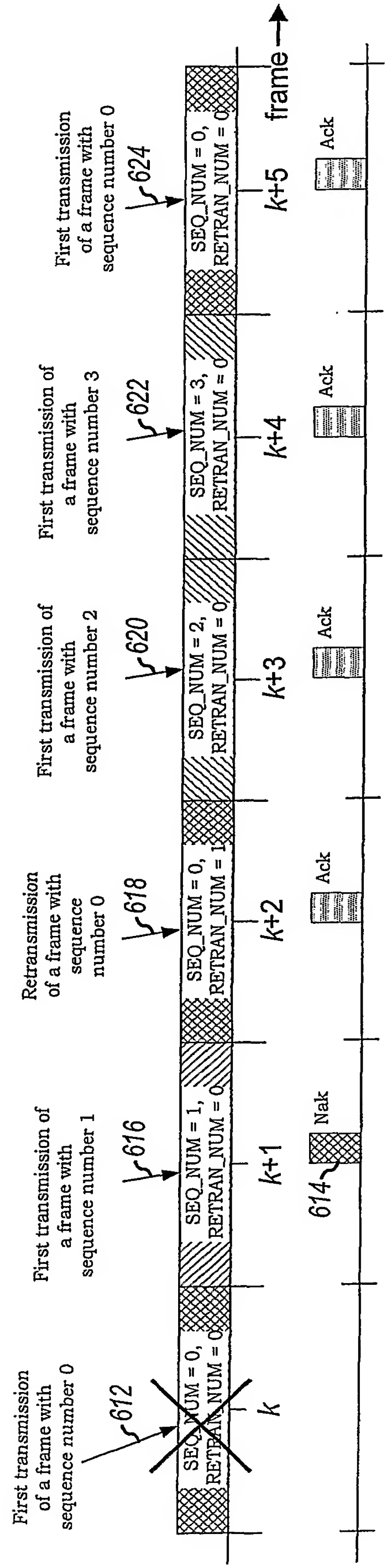
First transmission of a frame with sequence number 0
612
SEQ_NUM = 0, RETRAN_NUM = 0
k
First transmission of a frame with sequence number 1
616
SEQ_NUM = 1, RETRAN_NUM = 0
k+1
614
Nak
Retransmission of a frame with sequence number 0
618
SEQ_NUM = 0, RETRAN_NUM = 1
k+2
Ack
First transmission of a frame with sequence number 2
620
SEQ_NUM = 2, RETRAN_NUM = 0
k+3
Ack
First transmission of a frame with sequence number 3
622
SEQ_NUM = 3, RETRAN_NUM = 0
k+4
Ack
First transmission of a frame with sequence number 0
624
SEQ_NUM = 0, RETRAN_NUM = 0
k+5
Ack
frame

FIG. 6A

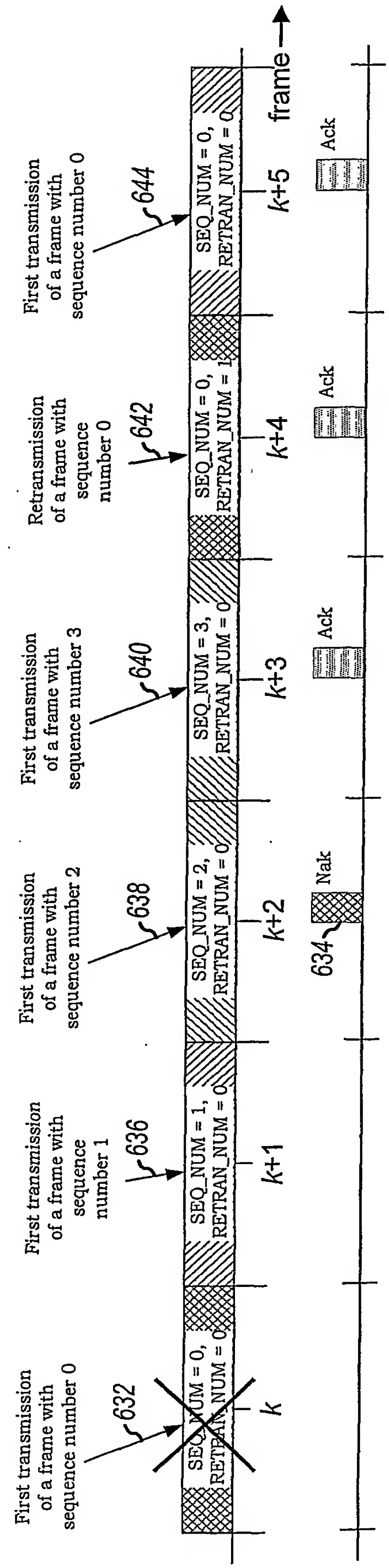
First transmission of a frame with sequence number 0
632
SEQ_NUM = 0, RETRAN_NUM = 0
k
First transmission of a frame with sequence number 1
636
SEQ_NUM = 1, RETRAN_NUM = 0
k+1
First transmission of a frame with sequence number 2
638
SEQ_NUM = 2, RETRAN_NUM = 0
k+2
634
Nak
First transmission of a frame with sequence number 3
640
SEQ_NUM = 3, RETRAN_NUM = 0
k+3
Ack
Retransmission of a frame with sequence number 0
642
SEQ_NUM = 0, RETRAN_NUM = 1
k+4
Ack
First transmission of a frame with sequence number 0
644
SEQ_NUM = 0, RETRAN_NUM = 0
k+5
Ack
frame

FIG. 6B

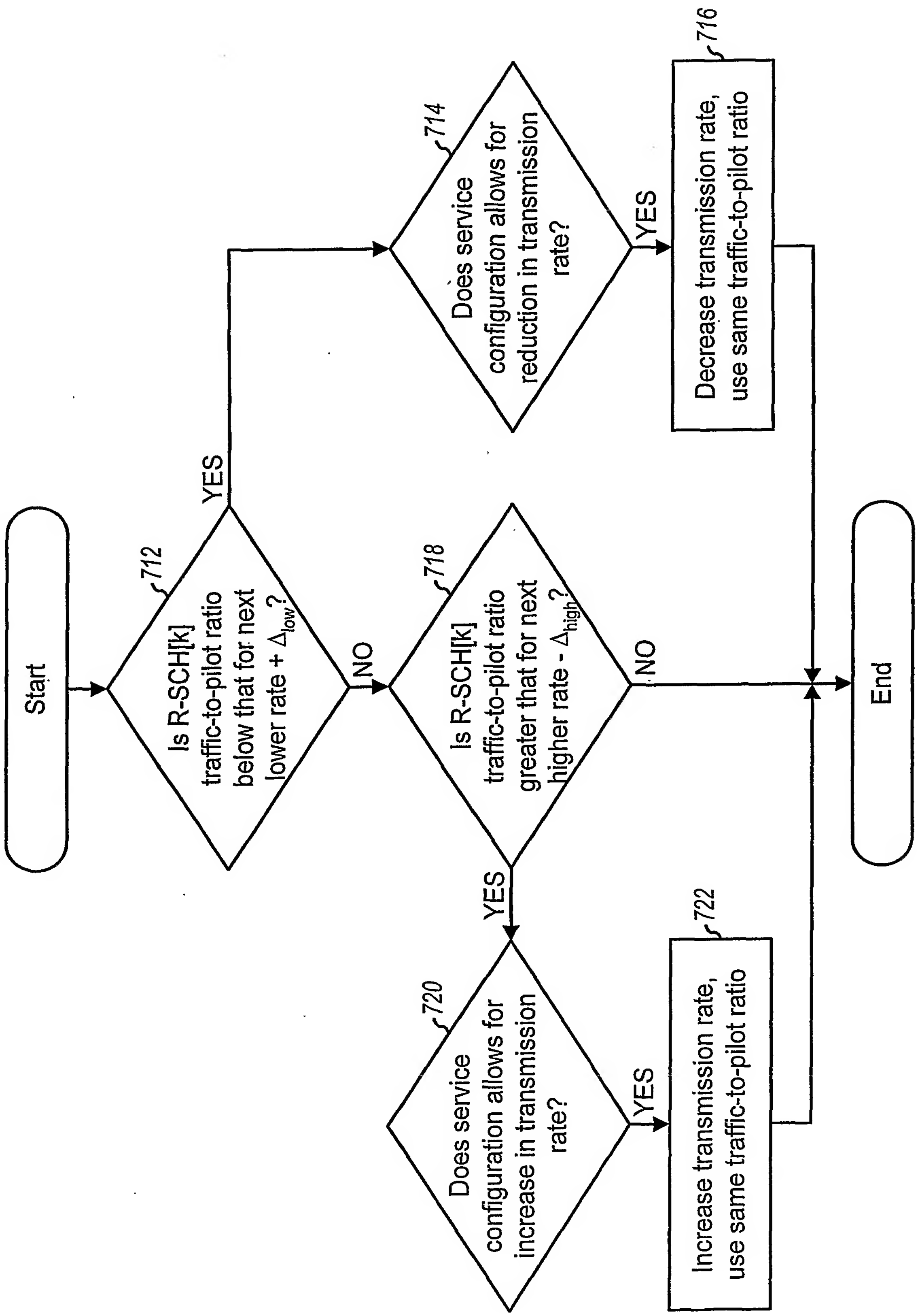
Start
712
Is R-SCH[k] traffic-to-pilot ratio below that for next lower rate + Δ_{low}?
YES
NO
714
Does service configuration allows for reduction in transmission rate?
YES
716
Decrease transmission rate, use same traffic-to-pilot ratio
718
Is R-SCH[k] traffic-to-pilot ratio greater that for next higher rate - Δ_{high}?
NO
YES
720
Does service configuration allows for increase in transmission rate?
YES
722
Increase transmission rate, use same traffic-to-pilot ratio
End

FIG. 7

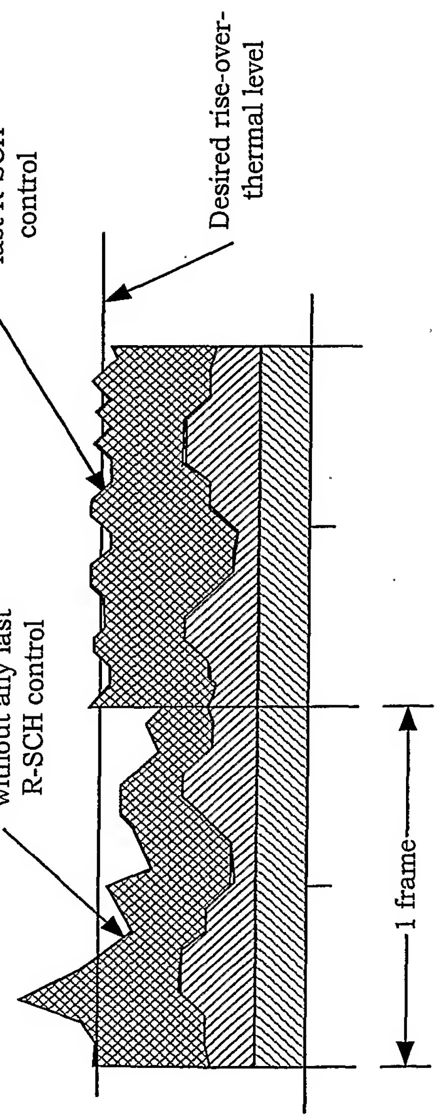
Power level with fast R-SCH control
Desired rise-over-thermal level
Power level without any fast R-SCH control
1 frame

FIG. 8

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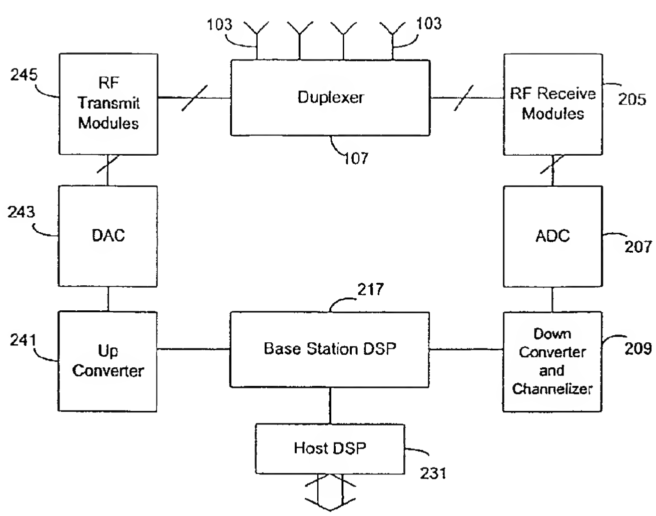
(54) Title: FREQUENCY DEPENDENT CALIBRATION OF A WIDEBAND RADIO SYSTEM USING NARROWBAND CHANNELS



(57) Abstract: A method and apparatus are provided that determine group delay for a set of transmit or receive chains over a wide frequency band without causing significant interference with simultaneous users of the system. In one embodiment, the invention includes an antenna array adapted to transmit and receive radio communications signals with a plurality of other terminals, the communications signals each using a particular minimum bandwidth, a transmit chain to transmit a calibration signal through the antenna array to a transponder on at least two different frequency bands within the minimum bandwidth, and a receive chain to receive through the antenna array a transponder signal from the transponder, the transponder signal being received on at least two different frequency bands and being based on the calibration signal. A signal processor determines a frequency dependent calibration vector based on the at least two frequency bands of the transponder signal as received through the receive chain.

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FREQUENCY DEPENDENT CALIBRATION OF A WIDEBAND RADIO SYSTEM USING NARROWBAND CHANNELS

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates generally to the field of digital signal communications and to receive and transmit chain calibration. More particularly, the invention relates to calibrating the group delay using narrowband signals at more than one frequency.

Description of the Related Art

Radio communications capacity can be greatly increased using directional, rather than omni-directional radio transmission. One way to transmit directional signals and directionally receive signals is by using beam forming and nulling through an array of antennas. The precision of the beam forming and nulling through the antenna array, can be improved if the transmit and receive chains are both calibrated. Calibration can be applied to the chain from the digital interface at baseband to the field radiated from or received at each antenna element. One way of making the calibration is to have a transponder separated from the antenna array listen to the output of the antenna array on a base station downlink frequency. The transponder receives a downlink calibration signal from the base station and then re-transmits it on an uplink frequency. By selecting appropriate signals to transmit and appropriate signals to receive, the base station can apply signal processing to estimate compensations in phase and amplitude to calibrate its transmit and receive chains.

A remote transponder calibration system is shown, for example, in U.S. Patent No. 5,546,090 to Roy, III et al. That patent describes calibrating a narrowband FDD (frequency division duplex) system for phase and amplitude at each transmit and receive chain. In an FDD system, unused time and frequency slots typically occur on occasion and these can be used to send and receive a narrowband calibration signal. In a typical spread spectrum system, however, there are no unused time and frequency slots to use for calibration. A spread spectrum system, for example a CDMA (code division multiple access) system, as opposed to FDMA (frequency division multiple access) and TDMA (time division multiple access) systems, has multiple users using the same radio channel at the same time. If the transponder is designed to receive and transmit the signal using the same spread spectrum channel that is used for traffic, then the additional energy added to the channel by calibration will reduce system

capacity. A typical transponder will receive all of the downlink traffic including the calibration signal, shift the frequency, amplify it and send all of the traffic back to the base station. This results in a very large amount of energy being sent by the transponder on the uplink and may effectively overpower all other traffic. As a result, calibration will affect both the downlink and uplink channel capacity. For calibrating group delay for a set of transmitters or receivers, a calibration signal normally is transmitted across a wider band of frequencies further ensuring interruptions to normal traffic.

BRIEF SUMMARY OF THE INVENTION

A method and apparatus are provided that determine group delay for a set of transmit or receive chains over a wide frequency band without causing significant interference with simultaneous users of the system. In one embodiment, the invention includes an antenna array adapted to transmit and receive radio communications signals with a plurality of other terminals, the communications signals each using a particular minimum bandwidth, a transmit chain to transmit a calibration signal through the antenna array to a transponder on at least two different frequency bands within the minimum bandwidth, and a receive chain to receive through the antenna array a transponder signal from the transponder, the transponder signal being received on at least two different frequency bands and being based on the calibration signal. A signal processor determines a frequency dependent calibration vector based on the at least two frequency bands of the transponder signal as received through the receive chain.

Other features of the present invention will be apparent from the accompanying drawings and from the detailed description that follows.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings in which like reference numerals refer to similar elements and in which:

Figure 1 is a block diagram illustrating an exemplary architecture of a wireless communication system base station appropriate for use with one embodiment of the present invention;

Figure 2 is a block diagram illustrating an exemplary architecture of a wireless transponder system appropriate for use with the base station of Figure 1;

Figure 3 is a process flow diagram showing the calibration of a receive chain; and

Figure 4 is a process flow diagram showing the calibration of a transmit chain.

DETAILED DESCRIPTION OF THE INVENTION

Introduction

In one embodiment, the present invention includes a method for calibrating the group delay of multiple transmit and receive chains of a wideband adaptive antenna base station using a narrowband transponder. In order to calibrate the group delay of the transmit and the receive chains, the base station transmits a different narrowband calibration signal over each of the transmit chains on at least two different frequencies in the downlink frequency band. These signals are then received by the narrowband transponder and retransmitted to the base station as narrowband signals in the wideband uplink frequency band. In this application, the radios in the adaptive antenna base station support wideband channels. However, in order to avoid creating any unnecessary interference, the calibration signals and the transponder signals are narrowband. In other words, the calibration signals occupy only narrow portions of the wideband channel. The transponder only receives in these narrow frequency bands and only retransmits the signals in correspondingly narrow portions of the uplink band.

Since the narrowband signals add only a small amount of energy to the wideband uplink and downlink channels, the calibration can be done while regular data traffic is being supported by the base station. The narrower the bandwidth of the calibration signals, the less will be the amount of energy that will be added to the system. For wideband spread spectrum systems the narrowband signals can easily be one tenth, or one hundredth as wide as the regular data traffic channels. For frequency division systems, the narrowband signals can still be one third to one fifth the width of the traffic channels. Proper selection of the signal power levels can further reduce the impact on regular traffic. Using multiple narrowband signals and transponder bands it is possible to calibrate for more general phase and gain variations as a function of

frequency. In a CDMA (Code Division Multiple Access) system, it is possible to design the CDMA system to be particularly insensitive to narrowband signals.

In one embodiment, the transponder only receives and re-transmits on narrow bands within the traffic bands of the wider band system to be calibrated. The system can have a set of wideband transmitters with antenna elements and a set of wideband receivers with antenna elements or a single set of elements can be common to the transmitters and the receivers. In both cases, system performance is normally improved with frequent calibration of the group delay for both the transmit chain and the receive chain. The group delay calibration vectors can be different for the receive chain and the transmit chain. In one example, the system has a multi-channel base station that communicates with multiple subscribers up to 10km away using CDMA with SDMA (spatial division multiple access). For this system, it has been found that calibrations every hour or two will noticeably improve performance. With such frequent calibrations, the impact of calibration on normal operations can be important. According to the present invention, the impact of calibration on normal operations can be minimized with a narrowband calibration transponder.

On each narrow frequency calibration band, different signals can be transmitted through two or more transmit chains. The signals can be differentiated, for example, by modulating different sequences onto the signals. In one embodiment, the sequences are orthogonal sequences to aid in demodulation. In another embodiment, the sequences are modulated onto the signals as spreading codes. This allows de-spreading codes to be used on the received signal so that the signal from each transmit chain can be distinguished. The transponder receives these signals and re-transmits them in the base station uplink band. The signals received by the base station can then be processed in order to measure any desired relative characteristics of the signals. For example, the signals can be used to find the relative phase and amplitude of the involved transmit chains and the relative phase and amplitude of all the receive chains. By transmitting different signals over the different transmit chains, the signals can be differentiated when received. This allows characteristics such as relative phase and amplitude to be estimated separately for each transmit chain. The characteristics can be used to determine spatial signatures for the uplink and downlink as well as to calculate frequency dependent calibration vectors. Combining phase measurements at different frequencies, a group delay calibration vector can be derived.

The relative phase and amplitude of the transmit chains can be estimated by receiving the different signals at a single antenna and then estimating the channel for each of the different signals transmitted over the different transmit chains. The relative phase and amplitude of the receive chains can be estimated by transmitting a single calibration signal over a single transmit chain and receiving it over the different receive chains. The channel received over each receive chain can then be estimated and compared to find spatial signatures and for calibration. As a result, if the calibration signal is sent once over all transmit chains and then the corresponding transponder signal is received through all receive chains, the entire array can be calibrated based on a single downlink and uplink burst. Since the transmit and receive calibration vector determinations need not be coupled to each other, performing both calibrations on the same burst increases efficiency and reduces the effects on traffic. If the calibration signal is transmitted on two or more different frequencies either at the same time or at different times close together, then the group delay can be derived.

As an alternative, just a few or even two of the transmit or receive chains can be calibrated at one time. If all the transmit or receive chains are not involved in each calibration measurement, then repeated calibration measurements with different sets of transmit or receive chains can be performed so that all relative phases and amplitudes can be measured among all the transmit and receive antennas. Accuracy is improved if there is a common transmit or receive chain in each of the measurements. This allows the measured phases and amplitudes to be related to each other with reference to the common chain. Typically, one of the receive chains is designated as a reference receive chain and calibration signals are measured in pairs with each receive chain being paired with the reference chain. Since the reference chain participates in every measurement, all of the other chains can be referenced to each other through the reference chain. After the receive chains are calibrated, a similar process is performed with the transmit chains being measured in pairs against the reference. It is not important which particular chain is selected to be the reference and the receive and transmit references need not have any relationship to each other. The calibration vectors can be expressed as variations from the reference or from any arbitrary standard such as an average, mean, or median of the differences between the receive or transmit chains, respectively.

In one embodiment, the present invention is implemented in an SDMA radio data communications system. In such a spatial division system, each terminal is

associated with a set of spatial parameters that relate to the radio communications channel between, for example, the base station and a user terminal. The spatial parameters comprise a spatial signature for each terminal. Using the spatial signature and arrayed antennas, the RF energy from the base station can be more precisely directed at a single user terminal, reducing interference with and lowering the noise threshold for other user terminals. Conversely, data received from several different user terminals at the same time can be resolved at lower receive energy levels. With spatial division antennas at the user terminals, the RF energy required for communications can be even less. The benefits are even greater for subscribers that are spatially separated from one another. The spatial signatures can include such things as the spatial location of the transmitters, the directions-of-arrival (DOAs), times-of-arrival (TOAs) and the distance from the base station.

Estimates of parameters such as signal power levels, DOAs, and TOAs can be determined using known training sequences placed in digital data streams for the purpose of channel equalization in conjunction with sensor (antenna) array information. This information is then used to calculate appropriate weights for spatial demultiplexers, multiplexers, and combiners. Extended Kalman filters or other types of linear filters, well known in the art, can be used to exploit the properties of the training sequences in determining spatial parameters. Further details regarding the use of spatial division and SDMA systems are described, for example, in U.S. Patents Nos. 5,828,658, issued Oct. 27, 1998 to Ottersten et al. and 5,642,353, issued June 24, 1997 to Roy, III et al.

Base Station Structure

The present invention relates to wireless communication systems and may be a fixed-access or mobile-access wireless network. It may use spatial division technology in combination with wideband multiple access systems, such as code division multiple access (CDMA), and other spread spectrum type systems. Figure 1 shows an example of a base station of a wireless communications system or network suitable for implementing the present invention. The system or network includes a number of subscriber stations, also referred to as remote terminals or user terminals, (not shown). The base station may be connected to a wide area network (WAN) through its host DSP 231 for providing any required data services and connections external to the immediate wireless system. To support spatial division, a plurality of

antennas 103 is used, for example four antennas, although other numbers of antennas may be selected.

The outputs of the antennas are connected to a duplexer switch 107, which in this CDMA system is a frequency switch. Alternatively, separate transmit and receive antenna arrays can be used, in which case the duplexer is not necessary. When receiving, the antenna outputs are connected via the switch 107 to RF (radio frequency) receive modules 205, and are mixed down and channelized in a down converter 207. The down converted signals are then sampled and converted to digital in an ADC (analog to digital converter) 209. This can be done using FIR (finite impulse response) filtering techniques. The invention can be adapted to suit a wide variety of RF and IF (intermediate frequency) carrier frequencies and bands.

There are, in the present example, four antenna channel outputs, one from each antenna receive module 205. The particular number of channels can be varied to suit network needs. For each of the four receive antenna channels, the four down-converted outputs from the four antennas are fed to a digital signal processor (DSP) device 217 for further processing, including calibration. According to one aspect of this invention, four Motorola DSP56300 Family DSPs can be used as channel processors, one per receive channel. The timeslot processors 217 monitor the received signal power and estimate the phase and time alignment. They also determine smart antenna weights for each antenna element. These are used in the spatial division multiple access scheme to determine a signal from a particular remote user and to demodulate the determined signal.

The output of the channel processors 217 is demodulated burst data. This data is sent to the host DSP 231 whose main function is to control all elements of the system and interface with the higher level processing. The higher level processing provides the signals required for communications in all the different control and service communication channels defined in the system's communication protocols. The host DSP 231 can be a Motorola DSP56300 Family DSP. In addition, channel processors send the determined receive weights for each user terminal to the host DSP 231.

The host DSP 231 maintains state and timing information, receives uplink burst data from the channel processors 217, and programs the channel processors 217. In addition, it decrypts, descrambles, checks error detecting code, and deconstructs bursts of the uplink signals, then formats the uplink signals to be sent for higher level processing in other parts of the base station. With respect to the other parts of the

base station, it formats service data and traffic data for further higher processing in the base station, receives downlink messages and traffic data from the other parts of the base station, processes the downlink bursts and formats and sends the downlink bursts to the transmit chain, discussed below.

Transmit data from the host DSP 231 is used to produce analog transmit outputs which are sent to the RF transmitter (tx) modules 245. Specifically, the received data bits are converted via a DAC (digital to analog converter) 241 to analog transmit waveforms and up-converted into a complex modulated signal, at an IF frequency in an upconverter 243. The analog waveforms are sent to the transmit modules 245. The transmit modules 245 up-convert the signals to the transmission frequency and amplify the signals. The amplified transmission signal outputs are sent to antennas 103 via the duplexer/time switch 107.

Narrowband Transponder Structure

Referring to Figure 2, an example of a remote transponder, suitable for use in implementing the present invention is shown. This transponder is designed to be inexpensive and simple. The particular transponder design shown can also be made in a small, portable, and lightweight package that can be used at the installation of the base station, if desired. The transponder can be mounted on a nearby fixture or even on the antenna mast that is used by the base station's antennas. Alternatively, the transponder can instead be operated as a special mode of a much more complex and fully functional user terminal. A second base station can also perform the transponder functions. The function of the transponder 118 is to receive a signal in the range of the wideband downlink channel, up-convert or down-convert it to the wideband uplink channel, filter it to select only a narrow frequency band, amplify it, and then re-transmit it as a signal in the range of the uplink channel. As mentioned above, frequency-shifting transponder 118 is only one possible example of a transponder suitable for use in calibration. The only general requirement for the transponder is that it transmits back a radio frequency signal that is somehow distinguishable from the signal it received. Besides frequency shifting the signal, the transponder can also time delay the signal, or more generally modulate it with various well-known modulation schemes. For a code division multiplex system, the transponder can also decode the received signal and encode it with a new spreading code for the uplink channel.

As shown in Figure 2, the calibration signal from the base station is received at the transponder antenna 122. A duplexer 140 separately routes signals received at the antenna to the receive chain beginning with a receive bandpass filter 126 and signals coming from the transmit chain, ending with a transmit bandpass filter 125. In the receive chain, signals coming from the transponder antenna after filtering 125 are routed to a low noise amplifier (LNA) 142. This amplified signal is then filtered again by a bandpass filter 144, which eliminates unwanted signals based on their frequencies. This filtered signal is then down-converted to IF (intermediate frequency) by a mixer 148 that combines the received signal with a LO (local oscillator signal) 146 waveform. The IF signal is processed through another bandpass filter 150 before upconversion for transmission. The channel filter 150 can be configured to have two or more passbands, one for each of the frequencies of the calibration signal from the base station.

A second mixer 149 combines the signals from the bandpass filter 150 and a second LO 147 to produce two new transmit signals at frequencies spaced apart from each other and within the uplink frequency band. These two new signals are bandpass filtered 145 and amplified in a power amplifier 143. The power amplifier is adjusted by a power feedback control loop 141 to reduce interference with other channels and smooth reception of the calibration signal at the base station. Another bandpass filter 125 eliminates the upper mixer product and any artifacts from the power amplifier, leaving only the lower mixer product which is a copy of the original input signal on the RF receive chain except for its frequency. This signal is connected to the duplexer 140 for transmission through the antenna element 122. The transponder shows, as an alternative, a separate transmit antenna element 123 and receive antenna element 124. If separate elements are used then the duplexer 140 is no longer required and the antennas can be directly coupled to the respective transmit and receive bandpass filters.

The transponder described above is designed to shift and transpond narrowband signals from the base station that are transmitted in the band for North American cellular CDMA communications, designated as IS-95 by the Telecommunications Industry Association (TIA). In some circumstances, it might be desirable to receive a wideband calibration signal over the complete CDMA channel and return it as a narrowband signal. Since most single channel communication bandwidths are too wide for practical filters at RF frequencies, such a single channel transponder would mix the RF frequency down to a lower intermediate frequency,

apply a narrowband filter at this intermediate frequency, and then mix the filtered signal back up to the desired RF frequency to be echoed back as a narrowband signal. In all other aspects, the wideband, single channel, transponder would behave and be constructed like the narrowband transponder described here.

To determine group delay, at least two frequencies of the calibration signal are desired. To return the two frequencies of the calibration signal, the transponder can be configured to return the two narrowband signals shifted in frequency. Alternatively an additional transponder with unique or some shared hardware can be used. Each transponder can be configured to receive and transmit only in a narrow band or to receive and transmit a broad range of different frequencies. The particular design of the multiple frequency transponder system will depend on the particular circumstances of the application and the communication system.

In operation, the base station DSP 217 generates a specialized narrowband calibration transmit signal on at least two frequencies which it transmits from the antenna array through the duplexer. The transponder receives the calibration transmit signal and echoes it back with the appropriate changes so that it will be received through the receive chain through the duplexer. In a conventional cellular CDMA system, the radio system uses different frequencies for transmit and receive. Thus, the transponder echoes back a signal on the uplink frequency band that is a frequency-shifted copy of the downlink signal it receives. The base station DSP acquires the echoed calibration signal on both frequencies through the receive chain and uses this received calibration signal along with knowledge of the transmit calibration signal to calculate group delay vectors which are then stored in a group delay calibration vector storage buffer.

For a CDMA cellular system, the system may be allocated a bandwidth from, e.g., 824 MHz to 835 MHz or from 835MHz to 849 MHz. The wideband channels within this range may be as narrow as 1.25 MHz or as wide as 5 MHz. In such a system, uplink and downlink frequency bands are typically separated from each other with a significant guard band so that they are separated by 1.25 MHz to 5 MHz. This is the amount by which the transponder must shift the calibration signal frequency to send it back to the base station. In other systems, the wideband uplink and downlink channels may be as wide as 40 MHz or more. The narrowband calibration signals on the other hand, would typically be from 0.01 MHz to 0.1 MHz wide. The spectral width of the calibration signal will be as small as reasonably convenient with readily available equipment at moderate cost. The narrower the signal, the less it will

interfere with existing traffic. However, as mentioned above, the narrowband signal must also be able to be transmitted and received by the wideband transmit and receive chains. The necessary bandwidth limitations will also depend on the particular system. For a system in which the wideband signals are 1.25 MHz wide, the narrowband signals will probably be much narrower than for a system in which the wideband signals are 40 MHz wide. The particular carrier frequencies used can also be adapted to suit the needs of the particular system. Currently, appropriate systems have carrier frequencies centered at frequencies ranging from 450 MHz to 2100 MHz. This range is expected to become greater as radio technologies and spectrum allocations change.

Calculation of Calibration Vectors

There are a variety of different ways to calculate and calibrate the phases and amplitudes of a multiple antenna array using narrowband signals and a transponder. U.S. Patents Nos. 5,546,090 issued August 13, 1996 to Roy, III et al., 5,930,243 issued July 27, 1999 to Parish et al. and 6,037,898 issued to Parish et al. show suitable approaches to calibration. Another approach is shown in International Application No. WO99157820, published November 11, 1999 of Boros et al. The disclosures of these references are hereby incorporated by reference herein.

With respect to calibrating the group delay for the transmit and receive chains of the base station, assuming identical RF propagation on the uplink and downlink, a single transponder or subscriber unit can be used together with its base station to carry out the calibration. However, the present invention enables the separate determination of the uplink and downlink signatures for the transponder or any subscriber unit. These spatial signatures include the effects of the electronic signal paths in the base station hardware and any differences between the uplink and downlink electronic signal paths for the transponder or subscriber unit. One use of such information is to determine separate calibrations for each subscriber unit when the RF propagation to and from the subscriber unit is different. Another use is for calibrating the base station, but rather than obtaining a single calibration vector using the base station and a single transponder, using several transponders to determine the single calibration vector.

In one embodiment, the single calibration vector is the average calibration vector. In another embodiment, it is the weighted average calibration vector. The weighting given to the estimate made using a particular subscriber unit will depend on

a measure of the quality of the signal received by that subscriber unit, so that estimates from subscriber units having better quality signals are weighed more in the weighted average. A method and apparatus for determining signal quality is disclosed in International Application No. WO99/40689, published August 12, 1999 of Yun.

In the architecture of Figures 1 and 2, the base station DSP generates a set of signals that are used for calibration. In one example, all antennas transmit different known calibration signals so that the channel from each transmit antenna to each receive antenna can be calculated. Generally, after subtracting out the components specific to the transponder's location, a receive calibration vector can then be estimated from the difference in phase and amplitude with frequency of the channels from one transmit antenna to each receive antenna. By averaging the results from all the transmit antennas, the calibration vector can be improved still further. Correspondingly, a calibration vector of the transmit chains can be estimated, after subtracting out the transponder specific components, from the relative phases and amplitudes of the channels from different transmit antennas to one of the receive antennas. Again, averaging the results from all the different receive antennas can improve the estimate.

Using the two or more narrow band transponder returns, the relative phase and amplitude of the transmit and receive chains can be calibrated at two frequencies within the base station downlink and uplink bands, respectively. The measurements can also be used for calibrating group delay and any other frequency dependent differences between the receive or transmit chains. Higher accuracy can be obtained if the two narrow frequency bands are placed some distance apart within the traffic bands. Higher accuracy can also be obtained by using more than two different frequencies. The best choice of calibration frequencies and numbers of different frequencies will depend on the bandwidth of the traffic bands and the desired accuracy.

Because a group delay can be regarded as equivalent to a phase ramp with a specific slope, the relative difference in group delay among the transmit and receive chains, respectively, can be calibrated using the phase measurements. This can be done by computing the slopes of the phase ramps based on the phase measurements at the two frequencies within the bands. Since there is an ambiguity in each phase measurement due to phase wrapping, the relative phase between the two measurement frequencies can only be determined to within a phase window of 360 degrees. As a result, any group delay changes and differences within the delay corresponding to a

phase shift of 360 degrees between the two measurement frequencies can be measured and compensated for.

The group delay can be determined directly from a phase calibration process. If the system is calibrating the various receive and transmit chains for phase and amplitude differences, the phase determinations from that process can be used to find the group delay. Group delay can also be determined using relative phase measurements that are calculated apart from any phase calibration process. The phase calibration will give a calibration vector with a calibration coefficient α_{ij} for each antenna i and frequency j. The actual phase φ_{ij} of an antenna i at frequency j can be expressed as $\varphi_{ij} = \alpha_{ij} + \delta_j$, where δ_j is an arbitrary unknown phase term that is common to all antennas at frequency j. The value of δ need not be known in order to calibrate the transmit or receive chain with respect to the other chains. Only the relative phases characterized by the α's is needed.

For group delay, the difference between different transmit or receive chains is used. For a single frequency j, this difference $\Delta\varphi_j$ between antenna i and i' can be expressed as $\Delta\varphi_j = \varphi_{ij} - \varphi_{i'j} = \alpha_{ij} + \delta_j - (\alpha_{i'j} + \delta_j) = \alpha_{ij} - \alpha_{i'j}$. The group delay between the antennas i and i' is obtained by comparing the difference in phase $\Delta\varphi$ at different frequencies. For frequencies j and j', the group delay is therefore proportional to $\Delta\varphi_j - \Delta\varphi_{j'}$. Using the phase calibration vectors α's at the two different frequencies, the relative group delay can quickly be determined.

In the process described above, δ_j the arbitrary unknown phase term that is common to all antennas at frequency j remains unknown. This term can also vary over time. For example if frequency f_1 is repeatedly measured, the measured signature can be expressed as $e^{j\varphi}\mathbf{a}_1$, where $\mathbf{a}$ is the measurement vector at frequency f_1 containing elements a_1, a_2, a_3, ... and the phase φ changes with each measurement. Alternatively, the measured phase can be normalized so that some component, for example, the first component, is real. in either case, the absolute phase is not measured.

As a result, the absolute group delay cannot easily be determined using the phase calibration values, however correcting for relative phase delays between the different transmit and receive chains significantly enhances performance. These relative phase differences constitute the differential phase delay between the transmit and receive chains of the system. Current digital signal processing technology can accommodate a frequency dependent phase variation from a single transmitter. If the phase variations from multiple transmitters can be aligned, then the variations in the

multiple transmitter system can be accommodated by the receiver in the same way as from a single transmitter. If the phase variations differ among the transmitters, the transmitted signal becomes much more difficult to resolve. Accordingly while a calibration that corrects for absolute group delay may be desirable in some applications, calibration for relative group delay is very useful. The more the differences between the transmit or alternatively, receive chains, can be reduced the higher the system's performance.

Using phase and amplitude measurements, calibration vectors can be formed and applied to transmissions by the base station. One approach uses spatial signatures from the receive chains of an antenna system and, using signatures at two different frequencies imposes a linear phase shift ramp. The spatial signatures can be made up of a vector or a set **a** of phase and amplitude measurements for each receive or transmit chain. They can be represented as $\mathbf{a}_j$ and $\mathbf{a}_{j'}$, where $\mathbf{a}_j$, for example, represents a set of values a_{j1}, a_{j2}, a_{j3}, ... a_M for each of M receive or transmit chains i = 1, 2, 3, ... M, at the frequency j. These two signatures are combined to derive the frequency dependent calibration factor $\mathbf{c}(f)$.

While a linear fit for $\mathbf{c}(f)$ provides for a simple and quick determination of the calibration vector using only two measured frequencies, as shown below, more frequencies can be measured and any variety of other curves or shapes can be matched to the measured results. The choice of an interpolation or curve matching algorithm as well as the choice of the number of different frequencies to measure will depend on a balance between calibration complexity and signal quality. The quality of the equalizers and the demodulators as well as the width of the frequency bandwidth of the system will likely also be considered among other factors.

To calibrate differential amplitude shifts with frequency, a frequency dependent amplitude calibration factor $| g_i(f) |$ for each antenna i = 1, ... M can be determined by linear interpolation:

$$| g_i(f) | = [(f-f_1)/(f_2-f_1)|a_{1,i}|] + [(f_2-f)/(f_2-f_1)|a_{2,i}|]$$

for $f_2 \geq f \geq f_1$, where f_2 corresponds to frequency j', f_1 corresponds to frequency j, $a_{1,i}$ corresponds to the phase and amplitude measurement for antenna i at frequency f_1 and $a_{2,i}$ corresponds to the phase amplitude measurement for antenna i at frequency f_2. Linear extrapolation can be used to extend the amplitude calibration factor outside the interval between the two measured frequencies f_1, f_2.

To determine a phase portion of the calibration vector $\mathbf{c}(f)$, a modified linear interpolation that compensates for the phase wrapping can be used. As mentioned

above, there is a relative phase window of 360 degrees or 2π, at which point, the phase wraps back around to zero. If angle (a) is an angle in degrees that can take any value from -180 degrees up to but not including 180, angle (a) $\in$ (-180, 180], and angle (a) corresponds to the complex number a, and a* is the complex conjugate of a, then the calibration phase $\varphi_i(f)$ for antenna i at frequency f can be expressed as shown below.

$$\varphi_i(f) = [\ (f-f_1)/(f_2-f_1)\ ]\ \text{angle}\ (a_{1,1})^* a_{2,i} + \text{angle}\ (a_{1,1})$$

for i = 1, ... M and the overall calibration factor is equal to the combination of the amplitude and phase calibration factors which can be expressed as shown below:

$$c_i(f) = |\ g_i(f)\ | e^{j(180/\pi)\varphi i(f)}$$

Method of Operation

An example of an operational process for calibrating a group of receive chains for group delay is shown in Figure 3. Other frequency dependent calibration vectors can be determined using a similar process. The calibration process typically includes calibrating the receive chain and the transmit chain with the same set of samples. Calibration of the transmit chains is shown in Figure 4. To begin a calibration cycle for the receive chain, the base station (BS) (see e.g. Figure 1) will generate a calibration signal. As discussed above, this is typically a narrowband signal at two or more frequencies. This narrowband transmit calibration signal is then transmitted from a single transmit chain of the base station 311. The transmission can occur at any time during the regular use of the base station for normal operation due to the small amount of additional energy added to the existing wideband data traffic by the narrowband signal. While only one transmit chain is required, transmitting from all of the transmit chains at once provides more samples for the receive calibration algorithms.

The transmitted narrowband calibration signal is received at the transponder 313, (see e.g. Figure 2). If the calibration signal is a wideband signal, it is converted to a set of at least two narrowband waveforms using appropriate bandpass filters as discussed above. If the signal has a particular spreading sequence or is modulated with a particular data or training sequence, this can be demodulated and a new signal can be modulated onto the signal. In one embodiment, the calibration signal is a narrrowband signal, which is simply received, shifted in frequency 315, and transmitted back to the base station 317. This approach simplifies the transponder and

eliminates many other potential causes of errors. The frequency shifted calibration signal can also be shifted to two or more different frequencies and retransmitted so that calibration can be performed across different narrow frequency bands. However, the same effect can be achieved with a simpler transponder by sending several different calibration signals from the base station, each at a different frequency for the downlink. Each signal will be shifted to a different frequency for the uplink.

The base station receives the transponder signal at each of its receive antenna chains 319. These received transponder signals are sampled for each receive antenna chain 321 and the samples can be used to measure any number of characteristics of the received signal. Each set of samples from each receive chain represents a different view of the same narrowband transponder signal. To enhance reception, the DSP 217 will typically use narrow bandpass filters to eliminate most of the data traffic signal energy and isolate the received transponder signal. The received transponder signal is used to calculate a set of phases, for example the α's discussed above and amplitudes 323 The calculation in support of group delay will typically be based on comparing the received transponder signal as it was received by each receive chain to each signal as received by each other receive chain. This is commonly done by measuring phases and amplitudes and using a covariance matrix, for example. As an alternative, the signal can be sampled at only two receive chains. This will allow the two selected chains to be calibrated against each other. By repeating the process for each possible combination or for each receive chain against a receive chain selected to be the reference, a set of relative phase measurements can be obtained.

The process of transmitting and receiving calibration signals described above can then be repeated and the results averaged or stored 325. Further relative phases and amplitudes are calculated using the additional data 327 and a group delay is calculated 328. This group delay is typically in the form of a calibration vector composed of a set of phase and amplitude correction factors for each transmit and receive chain, as discussed above. Alternatively, the resulting calibration vector can be applied and the process repeated to find a new vector that is used to adjust the first vector. By applying the adjusted calibration vector after each cycle, the calibration should become progressively more accurate until it converges on the limit of the calibration system's accuracy. The transmission, reception and computations can be repeated for different combinations of receive chains and even for different transponders. Over time, the characteristics of the receive chains can change and so the process can also be repeated in order to update the calibration vectors with

changing conditions. When the calibrations are done against a reference chain, pairing each receive chain against the reference, the reference chain's vectors can be set at one, or some other normalized set of values, so that the vectors for the other receive chains represent the variance from the reference chain. Alternatively, the vectors can represent the variance from any other value, for example an average, mean or median response.

Calibration of the transmit chain is done in a similar way as shown in Figure 4. As with the receive chain, a calibration signal is transmitted to the transponder. In this case, the calibration signal is transmitted from each of the base station's transmit chains 329. So that they can be distinguished from each other when received, each receive chain uses a different modulation sequence. As with the receive calibration, this signal is a narrowband signal at at least two different frequencies. The narrowband signal allows the transponder to have a simple construction.

The calibration signals are received at the transponder 331. Which then, as with the receive calibration, shifts the frequency of the received calibration signals 333. After that, the shifted calibration signals are transmitted back to the base station 335. It is again possible to change modulated sequences or spreading codes but the simplest transponder will take the narrowband signal that it receives in the downlink band and transmit it back as a virtually identical narrowband signal in the uplink band.

The base station receives the transponder signals this time at just one receive antenna chain 337. The received transponder signals are sampled 339 and then the unique modulated sequences are used to extract each transmit chain calibration signal 341 from the sampled waveform. As with the receive calibration, a narrow bandpass filter is typically used to isolate the transponder signal. For calibration purposes, the transmitted calibration signals from each transmit chain are compared to each other 343. In order to make it easier to distinguish the simultaneously received signals from the different transmit chains, the number of simultaneous transmit chains can be reduced. For example, one of the transmit chains can be designated as the reference and then each other transmit chain can transmit with the reference, one pair at a time, until all the transmit chains have been calibrated against the reference. This is similar to the pair-wise receive chain calibration mentioned above.

These comparisons become the basis for generating a set of relative phases and amplitudes 345. The process of sending and receiving calibration signals can then be repeated 347 and further relative phases and amplitudes computed 349 to

refine the results. Then, the transmit group delay calibration vector can be calculated for each transmit chain 351. In one embodiment, the calibration vector determined in the first round is applied to each transmit chain, and then the process is repeated. The next calibration cycle will lead to greater accuracy as the gross errors have already been compensated. This is similar to performing a coarse tuning process and then a fine-tuning process.

The present invention provides many advantages over the prior art. Calibrations can be performed using only a simple, inexpensive transponder. Both transmit and receive calibration can be determined in a single transaction and the method self-corrects for reference frequency offsets in the antenna array system. Accordingly, calibration in accordance with the present invention is inherently accurate. While the invention has been described primarily as a calibration of a base station using a remote transponder, it can be applied to remote user terminals that have multiple antennas. It can also be applied to any other type of wireless network with multiple antenna system whether one with base stations and remotes, equal peers or masters and slaves.

To improve the reception of regular traffic during calibration, it may be desirable to apply a notch filter at the base station to filter out the transponder signal bands. This would typically be a digital filter and can be turned off when no calibration signal is active. The subscriber units could similarly have a notch filter for the calibration signal from the base station.

In the description above, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that the present invention may be practiced without some of these specific details. In other instances, well-known structures and devices are shown in block diagram form.

The present invention includes various steps. The steps of the present invention may be performed by hardware components, such as those shown in Figures 1 and 2, or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor or logic circuits, such as a DSP programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software.

The present invention may be provided as a computer program product which may include a machine-readable medium having stored thereon instructions which may be used to program a computer (or other electronic devices) to perform a process

according to the present invention. The machine-readable medium may include, but is not limited to, floppy diskettes, optical disks, CD-ROMs, and magneto-optical disks, ROMs, RAMs, EPROMs, EEPROMs, magnet or optical cards, flash memory, or other type of media or machine-readable medium suitable for storing electronic instructions. Moreover, the present invention may also be downloaded as a computer program product, wherein the program may be transferred from a remote computer to a requesting computer by way of data signals embodied in a carrier wave or other propagation medium via a communication link (e.g., a modem or network connection).

Importantly, while the present invention has been described in the context of a wireless spread spectrum data system for mobile remote terminals, it can be applied to a wide variety of different wireless systems in which data is exchanged. Such systems include voice, video, music, broadcast and other types of data systems without external connections. The present invention can be applied to fixed user terminals as well as to low and high mobility terminals. Many of the methods are described herein in a basic form but steps can be added to or deleted from any of the methods and information can be added or subtracted from any of the described messages without departing from the basic scope of the present invention. It will be apparent to those skilled in the art that many further modifications and adaptations can be made. The particular embodiments are not provided to limit the invention but to illustrate it. The scope of the present invention is not to be determined by the specific examples provided above but only by the claims below.

CLAIMS

What is claimed is:

1. A radio communications system comprising:

an antenna array adapted to transmit and receive radio communications signals with a plurality of other terminals, the communications signals each using a particular minimum bandwidth;

a transmit chain to transmit a calibration signal through the antenna array to a transponder on at least two different frequency bands within the minimum bandwidth;

a receive chain to receive through the antenna array a transponder signal from the transponder, the transponder signal being received on at least two different frequency bands and being based on the calibration signal; and

a signal processor to determine a frequency dependent calibration vector based on the at least two frequency bands of the transponder signal as received through the receive chain.

2. The system of claim 1, wherein determining a frequency dependent calibration vector comprises comparing relative phases for the transponder signal at a first one of the at least two frequencies to relative phases for the transponder signal at a second one of the at least two frequencies to determine a group delay.

3. The system of claim 1, wherein the transponder signal is shifted in frequency as compared to the calibration signal.

4. The system of claim 1, further comprising measuring the relative phases and amplitudes of the transponder signal as received by the receive chain.

5. The system of claim 4:

wherein the receive chain comprises a plurality of receive chains;

wherein each receive chain receives the transponder signal; and

wherein the signal processor determines a group delay by comparing the relative phases of the transponder signal at each frequency as received by each receive chain.

6. The system of claim 5 wherein determining a frequency dependent calibration vector comprises determining a receive chain group delay by comparing a phase difference between at least two receive chains for the transponder signal at a first one of the at least two frequency bands to a phase difference between the same two receive chains for the transponder signal at a second one of the at least two frequency bands.

7. The system of claim 6, wherein one of the plurality of receive chains is selected as a reference receive chain and the group delay for each receive chain is characterized with respect to the reference receive chain.

8. The system of Claim 4 wherein the signal processor determines an uplink signature of the transponder at the antenna array at each frequency of the transponder signal using measured phases and amplitudes of the transponder signal and wherein the signal processor determines the frequency dependent calibration vector for the receive chain using the uplink signatures of the transponder.

9. The system of Claim 4 wherein the signal processor determines a downlink signature of the transmit chain at the transponder using measured phases and amplitudes at each frequency of the transponder signal and wherein the signal processor further determines the frequency dependent calibration vector for the transmit chain using the downlink signatures of the transmit chain.

10. The system of claim 1:

wherein the transmit chain comprises a plurality of transmit chains;

wherein each transmit chain transmits the calibration signal; and

wherein the signal processor determines a frequency dependent transmit calibration vector by comparing the relative phases of the transponder signal at each frequency of the transponder signal as received by each receive chain.

11. The system of claim 10, wherein the calibration signal comprises a plurality of signals, one from each transmit chain, each signal being individually identifiable based on a unique modulation sequence.

12. The system of claim 10 wherein determining a frequency dependent transmit calibration vector comprises comparing a phase difference between two transmit chains for the transponder signal at a first one of the at least two frequencies to a phase difference between the same two transmit chains for the transponder signal at a second one of the at least two frequencies to determine a group delay.

13. The system of Claim 12 wherein one of the plurality of transmit chains is selected as a reference chain and the group delay of each transmit chain is defined with respect to the reference chain.

14. A machine-readable medium having stored thereon data representing instructions which, when executed by a machine, cause the machine to perform operations comprising:

transmitting radio communications signals to a plurality of other terminals using a transmit chain, the communications signals each using a particular minimum transmit bandwidth;

receiving radio communications signals from a plurality of other terminals using a receive chain, the communications signals each using a particular minimum receive bandwidth;

transmitting a calibration signal through the transmit chain to a transponder on at least two different frequency bands within the minimum transmit bandwidth;

receiving a transponder signal through the receive chain from the transponder, the transponder signal being received on at least two different frequency bands within the minimum receive bandwidth and being based on the calibration signal; and

determining a frequency dependent calibration vector based on the at least two frequency bands of the transponder signal as received through the receive chain.

15. The medium of claim 14, wherein determining a frequency dependent calibration vector comprises comparing relative phases for the transponder signal at a first one of the at least two frequencies to relative phases for the transponder signal at a second one of the at least two frequencies to determine a group delay.

16. The medium of claim 14, wherein the transponder signal is shifted in frequency as compared to the calibration signal.

17. The medium of claim 14 wherein determining a frequency dependent calibration vector comprises determining a receive chain group delay by comparing a phase difference between at least two receive chains for the transponder signal at a first one of the at least two frequency bands to a phase difference between the same two receive chains for the transponder signal at a second one of the at least two frequency bands.

18. The medium of claim 14 wherein determining a frequency dependent transmit calibration vector comprises comparing a phase difference between two transmit chains for the transponder signal at a first one of the at least two frequencies to a phase difference between the same two transmit chains for the transponder signal at a second one of the at least two frequencies to determine a group delay.

19. A method comprising:

transmitting radio communications signals to a plurality of other terminals using a transmit chain, the communications signals each using a particular minimum transmit bandwidth;

receiving radio communications signals from a plurality of other terminals using a receive chain, the communications signals each using a particular minimum receive bandwidth;

transmitting a calibration signal through the transmit chain to a transponder on at least two different frequency bands within the minimum transmit bandwidth;

receiving a transponder signal through the receive chain from the transponder, the transponder signal being received on at least two different frequency bands within the minimum receive bandwidth and being based on the calibration signal; and

determining a frequency dependent calibration vector based on the at least two frequency bands of the transponder signal as received through the receive chain.

20. The method of claim 19, wherein determining a frequency dependent calibration vector comprises measuring the relative phases and amplitudes of the transponder signal as received by the receive chain.

21. The method of claim 19, wherein determining a frequency dependent calibration vector comprises determining a group delay by comparing the relative phases of the transponder signal at each frequency as received by a plurality of receive chains.

22. The method of claim 21, wherein one of the plurality of receive chains is selected as a reference receive chain and the group delay for each receive chain is characterized with respect to the reference receive chain.

23. The method of Claim 21 wherein determining a frequency dependent calibration vector comprises determining an uplink signature of the transponder at the receive chains at each frequency of the transponder signal using measured phases and amplitudes of the transponder signal and determining the frequency dependent calibration vector for the receive chains using the uplink signatures of the transponder.

24. The method of Claim 21 wherein the signal processor determining a frequency dependent calibration vector comprises determining a downlink signature of a plurality of transmit chains at the transponder using measured phases and amplitudes at each frequency of the transponder signal and determining the frequency dependent calibration vector for the transmit chains using the downlink signatures of the transmit chains.

25. The method of claim 19 wherein determining a frequency dependent calibration vector comprises determining a frequency dependent transmit calibration

vector by comparing the relative phases of the transponder signal at each frequency of the transponder signal as received by each of a plurality of receive chains.

26. The system of claim 1, wherein the system is a code division multiple access system.

27. The medium of claim 14, wherein the radio communications signals conform to a standard for code division multiple access.

28. The method of claim 19, wherein the radio communications signals conform to a standard for code division multiple access.

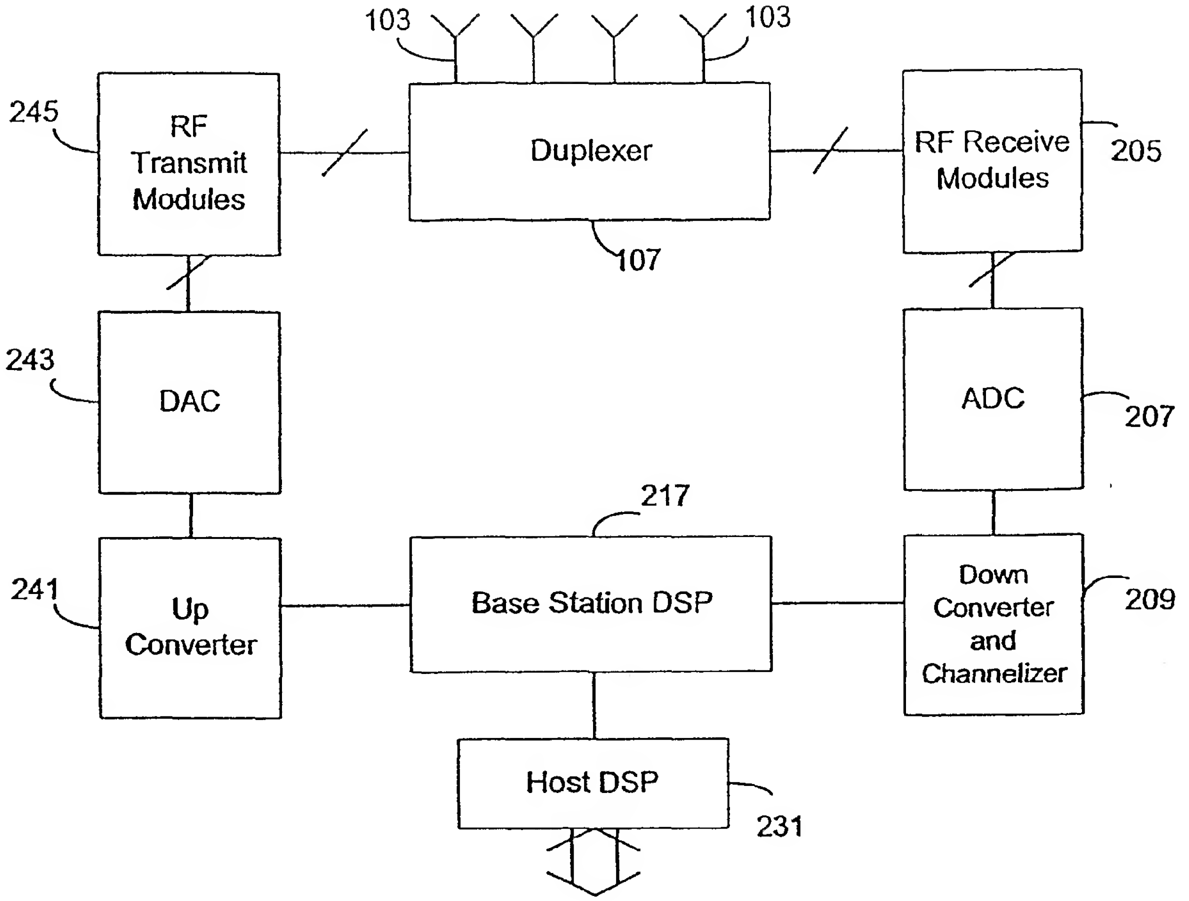
103
103
245
RF Transmit Modules
Duplexer
RF Receive Modules
205
107
243
DAC
ADC
207
217
241
Up Converter
Base Station DSP
Down Converter and Channelizer
209
Host DSP
231

Figure 1

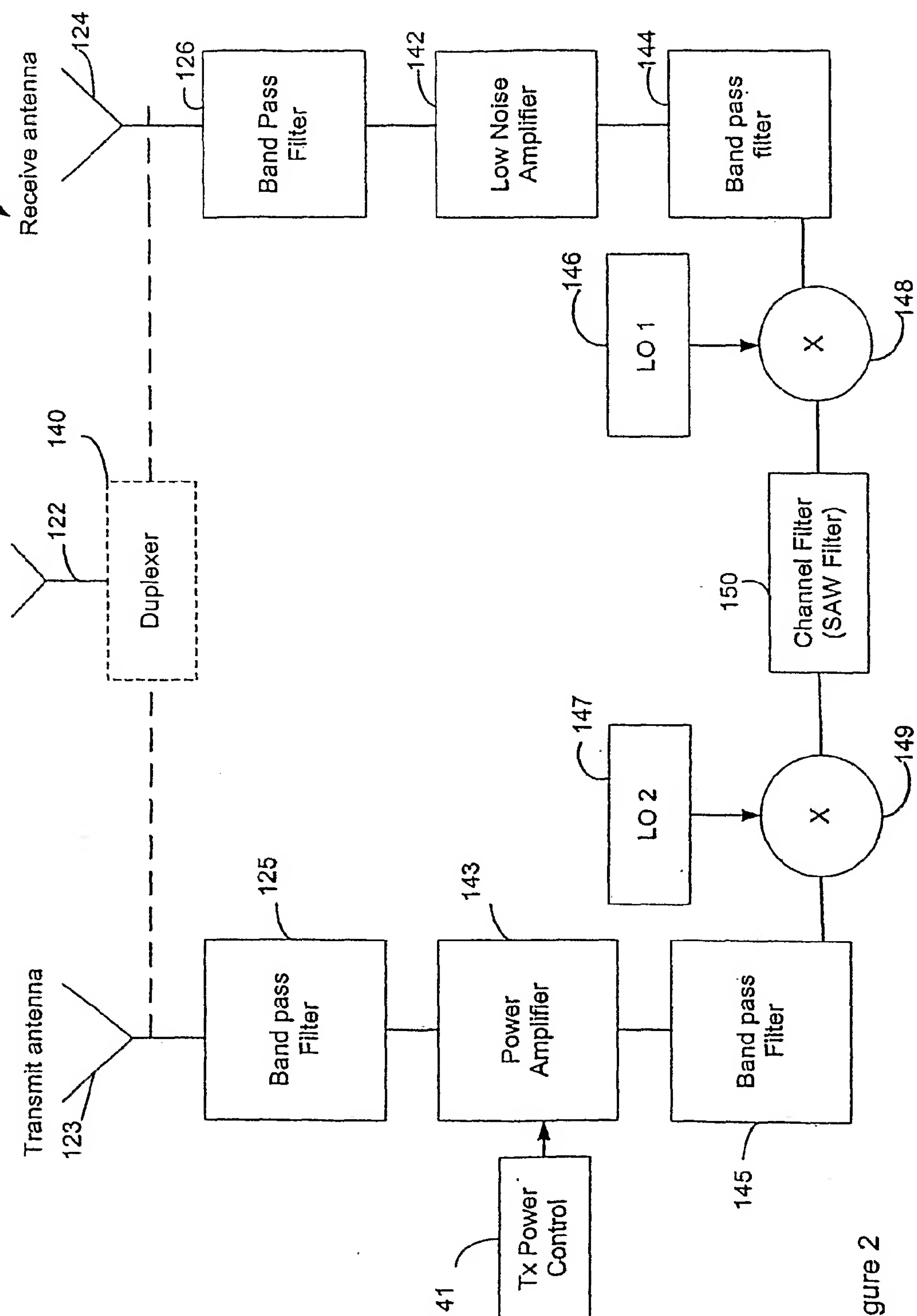
118
Receive antenna
124
126
Band Pass Filter
142
Low Noise Amplifier
144
Band pass filter
146
LO 1
148
140
122
Duplexer
150
Channel Filter (SAW Filter)
147
LO 2
149
Transmit antenna
123
125
Band pass Filter
143
Power Amplifier
Band pass Filter
145
141
Tx Power Control

Figure 2

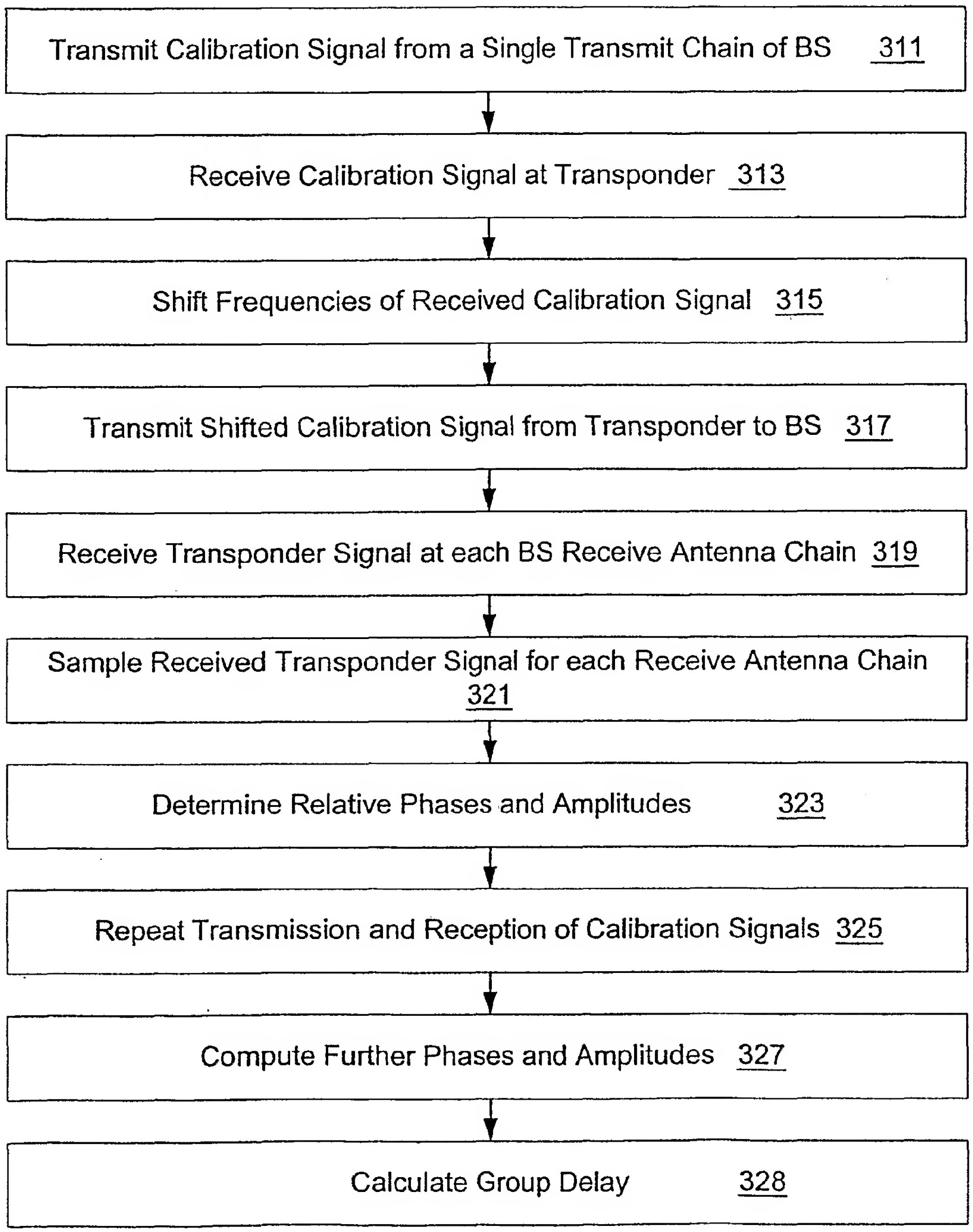
Transmit Calibration Signal from a Single Transmit Chain of BS 311
Receive Calibration Signal at Transponder 313
Shift Frequencies of Received Calibration Signal 315
Transmit Shifted Calibration Signal from Transponder to BS 317
Receive Transponder Signal at each BS Receive Antenna Chain 319
Sample Received Transponder Signal for each Receive Antenna Chain 321
Determine Relative Phases and Amplitudes 323
Repeat Transmission and Reception of Calibration Signals 325
Compute Further Phases and Amplitudes 327
Calculate Group Delay 328

Figure 3

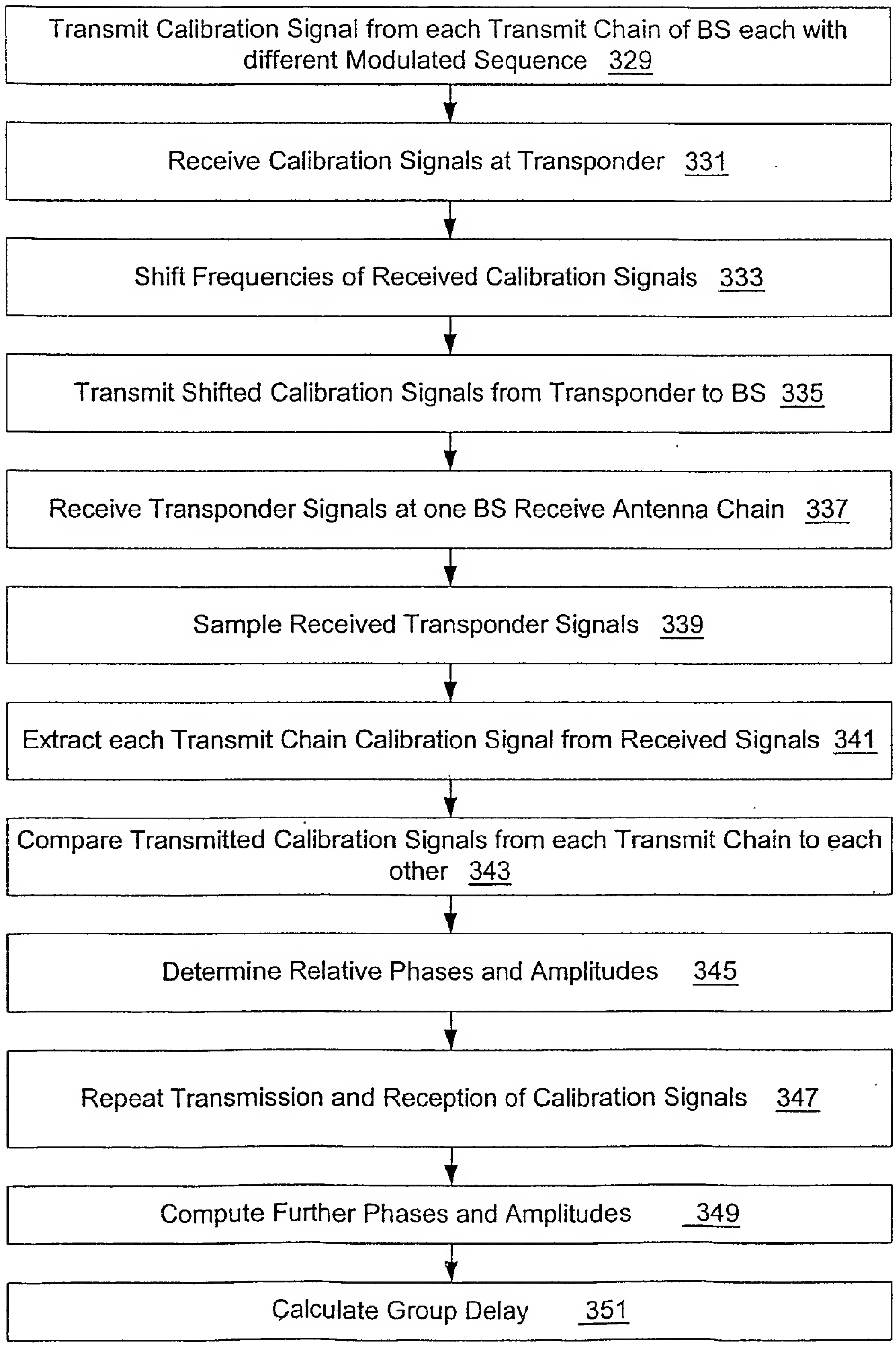
Transmit Calibration Signal from each Transmit Chain of BS each with different Modulated Sequence 329
Receive Calibration Signals at Transponder 331
Shift Frequencies of Received Calibration Signals 333
Transmit Shifted Calibration Signals from Transponder to BS 335
Receive Transponder Signals at one BS Receive Antenna Chain 337
Sample Received Transponder Signals 339
Extract each Transmit Chain Calibration Signal from Received Signals 341
Compare Transmitted Calibration Signals from each Transmit Chain to each other 343
Determine Relative Phases and Amplitudes 345
Repeat Transmission and Reception of Calibration Signals 347
Compute Further Phases and Amplitudes 349
Calculate Group Delay 351

Figure 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/30896

A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 546 090 A (ROY III RICHARD H ET AL) 13 August 1996 (1996-08-13) cited in the application abstract column 2, line 13-39 column 4, line 20 -column 8, line 53 figures 4-7 ---	1,3,4, 14,16, 19,20, 26-28
X	US 5 294 934 A (MATSUMOTO SOICHI) 15 March 1994 (1994-03-15) abstract column 4, line 63 -column 6, line 7 figure 1 --- -/--	1,14,19

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 December 2002	20/12/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Helms, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/30896

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 236 839 B1 (GU YUCONG ET AL) 22 May 2001 (2001-05-22) abstract column 1, line 37 -column 4, line 8 figure 1	1,14,19
A	US 6 037 898 A (BARRATT CRAIG H ET AL) 14 March 2000 (2000-03-14) cited in the application abstract column 9, line 49 -column 18, line 65 figure 2	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 02/30896

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			EP	1133836	A1	19-09-2001
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Published:
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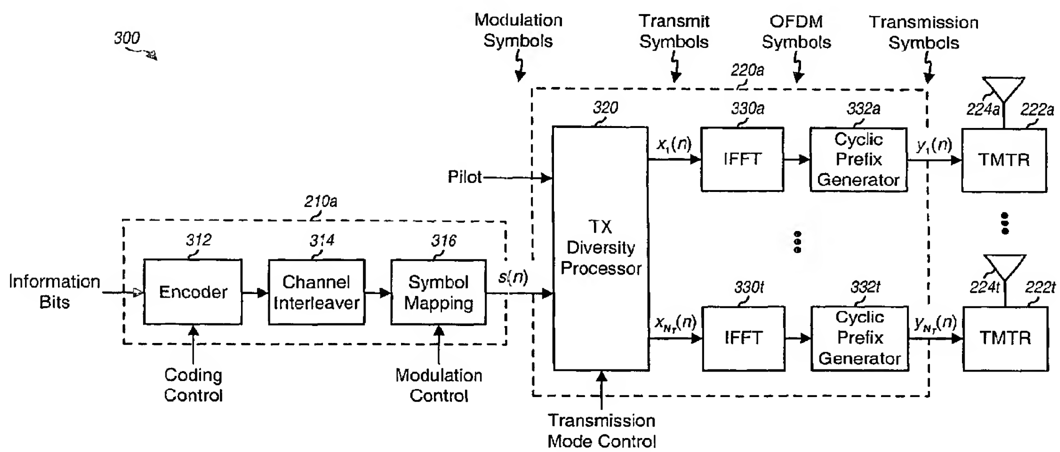
(54) Title: DIVERSITY TRANSMISSION MODES FOR MIMO OFDM COMMUNICATION SYSTEMS



(57) **Abstract:** Techniques for transmitting data using a number of diversity transmission modes to improve reliability. At a transmitter, for each of one or more data streams, a particular diversity transmission mode is selected for use from among a number of possible transmission modes. These transmission modes may include a frequency diversity transmission mode, a Walsh diversity transmission mode, a space time transmit diversity (STTD) transmission mode, and a Walsh-STTD transmission mode. Each diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof. Each data stream is coded and modulated to provide modulation symbols, which are further processed based on the selected diversity transmission mode to provide transmit symbols. For OFDM, the transmit symbols for all data streams are further OFDM modulated to provide a stream of transmission symbols for each transmit antenna used for data transmission.

WO 2004/002011 A1

DIVERSITY TRANSMISSION MODES FOR MIMO OFDM COMMUNICATION SYSTEMS

BACKGROUND

Field

[1001] The present invention relates generally to data communication, and more specifically to techniques for transmitting data using a number of diversity transmission modes in MIMO OFDM systems.

Background

[1002] Wireless communication systems are widely deployed to provide various types of communication such as voice, packet data, and so on. These systems may be multiple-access systems capable of supporting communication with multiple users either sequentially or simultaneously. This is achieved by sharing the available system resources, which may be quantified by the total available operating bandwidth and transmit power.

[1003] A multiple-access system may include a number of access points (or base stations) that communicate with a number of user terminals. Each access point may be equipped with one or multiple antennas for transmitting and receiving data. Similarly, each terminal may be equipped with one or multiple antennas.

[1004] The transmission between a given access point and a given terminal may be characterized by the number of antennas used for data transmission and reception. In particular, the access point and terminal pair may be viewed as (1) a multiple-input multiple-output (MIMO) system if multiple (N_T) transmit antennas and multiple (N_R) receive antennas are employed for data transmission, (2) a multiple-input single-output (MISO) system if multiple transmit antennas and a single receive antenna are employed, (3) a single-input multiple-output (SIMO) system if a single transmit antenna and multiple receive antennas are employed, or (4) a single-input single-output (SISO) system if a single transmit antenna and a single receive antenna are employed.

[1005] For a MIMO system, a MIMO channel formed by the N_T transmit and N_R receive antennas may be decomposed into N_S independent channels, with $N_S \leq \min\{N_T, N_R\}$. Each of the N_S independent channels is also referred to as a spatial

subchannel of the MIMO channel and corresponds to a dimension. The MIMO system can provide improved performance (e.g., increased transmission capacity and/or greater reliability) if the additional dimensionalities created by the multiple transmit and receive antennas are utilized. For a MISO system, only one spatial subchannel is available for data transmission. However, the multiple transmit antennas may be used to transmit data in a manner to improve the likelihood of correct reception by the receiver.

[1006] The spatial subchannels of a wideband system may encounter different channel conditions due to various factors such as fading and multipath. Each spatial subchannel may thus experience frequency selective fading, which is characterized by different channel gains at different frequencies of the overall system bandwidth. It is well known that frequency selective fading causes inter-symbol interference (ISI), which is a phenomenon whereby each symbol in a received signal acts as distortion to subsequent symbols in the received signal. The ISI distortion degrades performance by impacting the ability to correctly detect the received symbols.

[1007] To combat frequency selective fading, orthogonal frequency division multiplexing (OFDM) may be used to effectively partition the overall system bandwidth into a number of (N_F) subbands, which may also be referred to as OFDM subbands, frequency bins, or frequency sub-channels. Each subband is associated with a respective subcarrier upon which data may be modulated. For each time interval that may be dependent on the bandwidth of one subband, a modulation symbol may be transmitted on each of the N_F subbands.

[1008] For a multiple-access system, a given access point may communicate with terminals having different number of antennas at different times. Moreover, the characteristics of the communication channels between the access point and the terminals typically vary from terminal to terminal and may further vary over time, especially for mobile terminals. Different transmission schemes may then be needed for different terminals depending on their capabilities and requirements.

[1009] There is therefore a need in the art for techniques for transmitting data using a number of diversity transmission modes depending on the capability of the receiver device and the channel conditions.

SUMMARY

[1010] Techniques are provided herein for transmitting data in a manner to improve the reliability of data transmission. A MIMO OFDM system may be designed to support a number of modes of operation for data transmission. These transmission modes may include diversity transmission modes, which may be used to achieve higher reliability for certain data transmission (e.g., for overhead channels, poor channel conditions, and so on). The diversity transmission modes attempt to achieve transmit diversity by establishing orthogonality among multiple signals transmitted from multiple transmit antennas. Orthogonality among the transmitted signals may be attained in frequency, time, space, or any combination thereof. The transmission modes may also include spatial multiplexing transmission modes and beam steering transmission modes, which may be used to achieve higher bit rates under certain favorable channel conditions.

[1011] In an embodiment, a method is provided for processing data for transmission in a wireless (e.g., MIMO OFDM) communication system. In accordance with the method, a particular diversity transmission mode to use for each of one or more data streams is selected from among a number of possible transmission modes. Each diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof. Each data stream is coded and modulated based on coding and modulation schemes selected for the data stream to provide modulation symbols. The modulation symbols for each data stream are further processed based on the selected diversity transmission mode to provide transmit symbols. For OFDM, the transmit symbols for all data streams are further OFDM modulated to provide a stream of transmission symbols for each of one or more transmit antennas used for data transmission. Pilot symbols may also be multiplexed with the modulation symbols using frequency division multiplexing (FDM), time division multiplexing (TDM), code division multiplexing (CDM), or any combination thereof.

[1012] The transmission modes may include, for example, (1) a frequency diversity transmission mode that redundantly transmits modulation symbols over multiple OFDM subbands, (2) a Walsh diversity transmission mode that transmits each modulation symbol over N_T OFDM symbol periods, where N_T is the number of transmit antennas used for data transmission, (3) a space time transmit diversity (STTD) transmission

mode that transmits modulation symbols over multiple OFDM symbol periods and multiple transmit antennas, and (4) a Walsh-STTD transmission mode that transmits modulation symbols using a combination of Walsh diversity and STTD. For the Walsh diversity and Walsh-STTD transmission modes, the same modulation symbols may be redundantly transmitted over all transmit antennas or different modulation symbols may be transmitted over different transmit antennas.

[1013] Each data stream may be for an overhead channel or targeted for a specific receiver device. The data rate for each user-specific data stream may be adjusted based on the transmission capability of the receiver device. The transmit symbols for each data stream are transmitted on a respective group of one or more subbands.

[1014] In another embodiment, a method is provided for processing a data transmission at a receiver of a wireless communication system. In accordance with the method, the particular diversity transmission mode used for each of one or more data streams to be recovered is initially determined. The diversity transmission mode used for each is selected from among a number of possible transmission modes. Received symbols for each data stream are then processed based on the diversity transmission mode used for the data stream to provide recovered symbols, which are estimates of modulation symbols transmitted from a transmitter for the data stream. The recovered symbols for each data stream are further demodulated and decoded to provide decoded data for the data stream.

[1015] Various aspects and embodiments of the invention are described in further detail below. The invention further provides methods, transmitter units, receiver units, terminals, access points, systems, and other apparatuses and elements that implement various aspects, embodiments, and features of the invention, as described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[1016] The features, nature, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

[1017] FIG. 1 is a diagram of a multiple-access system that supports a number of users;

[1018] FIG. 2 is a block diagram of an embodiment of an access point and two terminals;

[1019] FIG. 3 is a block diagram of a transmitter unit;

[1020] FIG. 4 is a block diagram of a TX diversity processor that may be used to implement the frequency diversity scheme;

[1021] FIG. 5 is a block diagram of a TX diversity processor that may be used to implement the Walsh diversity scheme;

[1022] FIG. 6 is a block diagram of a TX diversity processor that may be used to implement the STTD scheme;

[1023] FIG. 7 is a block diagram of a TX diversity processor that may be used to implement a repeated Walsh-STTD scheme;

[1024] FIG. 8 is a block diagram of a TX diversity processor that may be used to implement a non-repeated Walsh-STTD scheme;

[1025] FIG. 9 is a block diagram of a receiver unit;

[1026] FIG. 10 is a block diagram of an RX diversity processor;

[1027] FIG. 11 is a block diagram of an RX antenna processor within the RX diversity processor and which may be used for the Walsh diversity scheme; and

[1028] FIG. 12 is a block diagram of an RX subband processor within the RX antenna processor and which may be used for the repeated and non-repeated Walsh-STTD schemes.

DETAILED DESCRIPTION

[1029] **FIG. 1** is a diagram of a multiple-access system 100 that supports a number of users. System 100 includes one or more access points (AP) 104 that communicate with a number of terminals (T) 106 (only one access point is shown in FIG. 1 for simplicity). An access point may also be referred to as a base station, a UTRAN, or some other terminology. A terminal may also be referred to as a handset, a mobile station, a remote station, user equipment (UE), or some other terminology. Each terminal 106 may concurrently communicate with multiple access points 104 when in soft handoff (if soft handoff is supported by the system).

[1030] In an embodiment, each access point 104 employs multiple antennas and represents (1) the multiple-input (MI) for a downlink transmission from the access point to a terminal and (2) the multiple-output (MO) for an uplink transmission from the terminal to the access point. A set of one or more terminals 106 communicating with a given access point collectively represents the multiple-output for the downlink transmission and the multiple-input for the uplink transmission.

[1031] Each access point 104 can communicate with one or multiple terminals 106, either concurrently or sequentially, via the multiple antennas available at the access point and the one or more antennas available at each terminal. Terminals not in active communication may receive pilots and/or other signaling information from the access point, as shown by the dashed lines for terminals 106e through 106h in FIG. 1.

[1032] For the downlink, the access point employs N_T antennas and each terminal employs 1 or N_R antennas for reception of one or more data streams from the access point. In general, N_R can be different for different multi-antenna terminals and can be any integer. A MIMO channel formed by the N_T transmit antennas and N_R receive antennas may be decomposed into N_S independent channels, with $N_S \leq \min\{N_T, N_R\}$. Each such independent channel is also referred to as a spatial subchannel of the MIMO channel. The terminals concurrently receiving downlink data transmission need not be equipped with equal number of receive antennas.

[1033] For the downlink, the number of receive antennas at a given terminal may be equal to or greater than the number of transmit antennas at the access point (i.e., $N_R \geq N_T$). For such a terminal, the number of spatial subchannels is limited by the number of transmit antennas at the access point. Each multi-antenna terminal communicates with the access point via a respective MIMO channel formed by the access point's N_T transmit antennas and its own N_R receive antennas. However, even if multiple multi-antenna terminals are selected for concurrent downlink data transmission, only N_S spatial subchannels are available regardless of the number of terminals receiving the downlink transmission.

[1034] For the downlink, the number of receive antennas at a given terminal may also be less than the number of transmit antennas at the access point (i.e., $N_R < N_T$). For example, a MISO terminal is equipped with a single receive antenna ($N_R = 1$) for downlink data transmission. The access point may then employ diversity, beam

steering, space division multiple access (SDMA), or some other transmission techniques to communicate simultaneously with one or multiple MISO terminals.

[1035] For the uplink, each terminal may employ a single antenna or multiple antennas for uplink data transmission. Each terminal may also utilize all or only a subset of its available antennas for uplink transmission. At any given moment, the N_T transmit antennas for the uplink are formed by all antennas used by one or more active terminals. The MIMO channel is then formed by the N_T transmit antennas from all active terminals and the access point's N_R receive antennas. The number of spatial subchannels is limited by the number of transmit antennas, which is typically limited by the number of receive antennas at the access point (i.e., $N_S \leq \min\{N_T, N_R\}$).

[1036] **FIG. 2** is a block diagram of an embodiment of access point 104 and two terminals 106. On the downlink, at access point 104, various types of traffic data such as user-specific data from a data source 208, signaling, and so on are provided to a transmit (TX) data processor 210. Processor 210 then formats and encodes the traffic data based on one or more coding schemes to provide coded data. The coded data is then interleaved and further modulated (i.e., symbol mapped) based on one or more modulation schemes to provide modulation symbols (i.e., modulated data). The data rate, coding, interleaving, and symbol mapping may be determined by controls provided by a controller 230 and a scheduler 234. The processing by TX data processor 210 is described in further detail below.

[1037] A transmit processor 220 then receives and processes the modulation symbols and pilot data to provide transmission symbols. The pilot data is typically known data processed in a known manner, if at all. In a specific embodiment, the processing by transmit processor 220 includes (1) processing the modulation symbols based on one or more transmission modes selected for use for data transmission to the terminals to provide transmit symbols and (2) OFDM processing the transmit symbols to provide transmission symbols. The processing by transmit processor 220 is described in further detail below.

[1038] Transmit processor 220 provides N_T streams of transmission symbols to N_T transmitters (TMTR) 222a through 222t, one transmitter for each antenna used for data transmission. Each transmitter 222 converts its transmission symbol stream into one or more analog signals and further conditions (e.g., amplifies, filters, and frequency

upconverts) the analog signals to generate a respective downlink modulated signal suitable for transmission over a wireless communication channel. Each downlink modulated signal is then transmitted via a respective antenna 224 to the terminals.

[1039] At each terminal 106, the downlink modulated signals from multiple transmit antennas of the access point are received by one or multiple antennas 252 available at the terminal. The received signal from each antenna 252 is provided to a respective receiver (RCVR) 254. Each receiver 254 conditions (e.g., filters, amplifies, and frequency downconverts) its received signal and further digitizes the conditioned signal to provide a respective stream of samples.

[1040] A receive processor 260 then receives and processes the streams of samples from all receivers 254 to provide recovered symbols (i.e., demodulated data). In a specific embodiment, the processing by receive processor 260 includes (1) OFDM processing the received transmission symbols to provide received symbols, and (2) processing the received symbols based on the selected transmission mode(s) to obtain recovered symbols. The recovered symbols are estimates of the modulation symbols transmitted by the access point. The processing by receive processor 260 is described in further detail below.

[1041] A receive (RX) data processor 262 then symbol demaps, deinterleaves, and decodes the recovered symbols to obtain the user-specific data and signaling transmitted on the downlink for the terminal. The processing by receive processor 260 and RX data processor 262 is complementary to that performed by transmit processor 220 and TX data processor 210, respectively, at the access point.

[1042] On the uplink, at terminal 106, various types of traffic data such as user-specific data from a data source 276, signaling, and so on are provided to a TX data processor 278. Processor 278 codes the different types of traffic data in accordance with their respective coding schemes to provide coded data and further interleaves the coded data. A modulator 280 then symbol maps the interleaved data to provide modulated data, which is provided to one or more transmitters 254. OFDM may or may not be used for the uplink data transmission, depending on the system design. Each transmitter 254 conditions the received modulated data to generate a respective uplink modulated signal, which is then transmitted via an associated antenna 252 to the access point.

[1043] At access point 104, the uplink modulated signals from one or more terminals are received by antennas 224. The received signal from each antenna 224 is provided to a receiver 222, which conditions and digitizes the received signal to provide a respective stream of samples. The sample streams from all receivers 222 are then processed by a demodulator 240 and further decoded (if necessary) by an RX data processor 242 to recover the data transmitted by the terminals.

[1044] Controllers 230 and 270 direct the operation at the access point and the terminal, respectively. Memories 232 and 272 provide storage for program codes and data used by controllers 230 and 270, respectively. Scheduler 234 schedules the data transmission on the downlink (and possibly the uplink) for the terminals.

[1045] For clarity, various transmit diversity schemes are specifically described below for downlink transmission. These schemes may also be used for uplink transmission, and this is within the scope of the invention. Also for clarity, in the following description, subscript "i" is used as an index for the receive antennas, subscript "j" is used as an index for the transmit antennas, and subscript "k" is used as an index for the subbands in the MIMO OFDM system.

Transmitter Unit

[1046] **FIG. 3** is a block diagram of a transmitter unit 300, which is an embodiment of the transmitter portion of access point 104. Transmitter unit 300 includes (1) a TX data processor 210a that receives and processes traffic and pilot data to provide modulation symbols and (2) a transmit processor 220a that further processes the modulation symbols to provide N_T streams of transmission symbols for the N_T transmit antennas. TX data processor 210a and transmit processor 220a are one embodiment of TX data processor 210 and transmit processor 220, respectively, in FIG. 2.

[1047] In the specific embodiment shown in FIG. 3, TX data processor 210a includes an encoder 312, a channel interleaver 314, and a symbol mapping element 316. Encoder 312 receives and codes the traffic data (i.e., the information bits) based on one or more coding schemes to provide coded bits. The coding increases the reliability of the data transmission.

[1048] In an embodiment, the user-specific data for each terminal and the data for each overhead channel may be considered as distinct data streams. The overhead

channels may include broadcast, paging, and other common channels intended to be received by all terminals. Multiple data streams may also be sent to a given terminal. Each data stream may be coded independently based on a specific coding scheme selected for that data stream. Thus, a number of independently coded data streams may be provided by encoder 312 for different overhead channels and terminals.

[1049] The specific coding scheme to be used for each data stream is determined by a coding control from controller 230. The coding scheme for each terminal may be selected, for example, based on feedback information received from the terminal. Each coding scheme may include any combination of forward error detection (FED) codes (e.g., a cyclic redundancy check (CRC) code) and forward error correction (FEC) codes (e.g., a convolutional code, a Turbo code, a block code, and so on). A coding scheme may also designate no coding at all. Binary or trellis-based codes may also be used for each data stream. Moreover, with convolutional and Turbo codes, puncturing may be used to adjust the code rate. More specifically, puncturing may be used to increase the code rate above the base code rate.

[1050] In a specific embodiment, the data for each data stream is initially partitioned into frames (or packets). For each frame, the data may be used to generate a set of CRC bits for the frame, which is then appended to the data. The data and CRC bits for each frame are then coded with either a convolutional code or a Turbo code to generate the coded data for the frame.

[1051] Channel interleaver 314 receives and interleaves the coded bits based on one or more interleaving schemes. Typically, each coding scheme is associated with a corresponding interleaving scheme. In this case, each independently coded data stream would be interleaved separately. The interleaving provides time diversity for the coded bits, permits each data stream to be transmitted based on an average SNR of the subbands and spatial subchannels used for the data stream, combats fading, and further removes correlation between coded bits used to form each modulation symbol.

[1052] With OFDM, the channel interleaver may be designed to distribute the coded data for each data stream over multiple subbands of a single OFDM symbol or possibly over multiple OFDM symbols. The objective of the channel interleaver is to randomize the coded data so that the likelihood of consecutive coded bits being corrupted by the communication channel is reduced. When the interleaving interval for a given data

stream spans a single OFDM symbol, the coded bits for the data stream are randomly distributed across the subbands used for the data stream to exploit frequency diversity. When the interleaving interval spans multiple OFDM symbols, the coded bits are randomly distributed across the data-carrying subbands and the multi-symbol interleaving interval to exploit both frequency and time diversity. For a wireless local area network (WLAN), the time diversity realized by interleaving over multiple OFDM symbols may not be significant if the minimum expected coherence time of the communication channel is many times longer than the interleaving interval.

[1053] Symbol mapping element 316 receives and maps the interleaved data in accordance with one or more modulation schemes to provide modulation symbols. A particular modulation scheme may be used for each data stream. The symbol mapping for each data stream may be achieved by grouping sets of q_m coded and interleaved bits to form data symbols (each of which may be a non-binary value), and mapping each data symbol to a point in a signal constellation corresponding to the modulation scheme selected for use for that data stream. The selected modulation scheme may be QPSK, M-PSK, M-QAM, or some other modulation scheme. Each mapped signal point is a complex value and corresponds to an M_m-ary modulation symbol, where M_m corresponds to the specific modulation scheme selected for data stream m and $\mathrm{M}_m = 2^{q_m}$. Symbol mapping element 316 provides a stream of modulation symbols for each data stream. The modulation symbol streams for all data streams are collectively shown as modulation symbol stream $s(n)$ in FIG. 3.

[1054] Table 1 lists various coding and modulation schemes that may be used to achieve a range of spectral efficiencies (or bit rates) using convolutional and Turbo codes. Each bit rate (in unit of bits/sec/Hertz or bps/Hz) may be achieved using a specific combination of code rate and modulation scheme. For example, a bit rate of one-half may be achieved using a code rate of 1/2 and BPSK modulation, a bit rate of one may be achieved using a code rate of 1/2 and QPSK modulation, and so on.

[1055] In Table 1, BPSK, QPSK, 16-QAM, and 64-QAM are used for the listed bit rates. Other modulation schemes such as DPSK, 8-PSK, 32-QAM, 128-QAM, and so on, may also be used and are within the scope of the invention. DPSK (differential phase-shift keying) may be used when the communication channel is difficult to track since a coherence reference is not needed at the receiver to demodulate a DPSK

modulated signal. For OFDM, modulation may be performed on a per subband basis, and the modulation scheme to be used for each subband may be independently selected.

Table 1

Convolutional Code			Turbo Code		
Efficiency (bps/Hz)	Code rate	Modulation	Efficiency (bps/Hz)	Code rate	Modulation
0.5	1/2	BPSK	0.5	1/2	BPSK
1.0	1/2	QPSK	1.0	1/2	QPSK
1.5	3/4	QPSK	1.5	3/4	QPSK
2.0	1/2	16-QAM	2.0	1/2	16-QAM
2.67	2/3	16-QAM	2.5	5/8	16-QAM
3.0	3/4	16-QAM	3.0	3/4	16-QAM
3.5	7/8	16-QAM	3.5	7/12	64-QAM
4.0	2/3	64-QAM	4.0	2/3	64-QAM
4.5	3/4	64-QAM	4.5	3/4	64-QAM
5.0	5/6	64-QAM	5.0	5/6	64-QAM

Other combinations of code rates and modulation schemes may also be used to achieve the various bit rates, and this is also within the scope of the invention.

[1056] In the specific embodiment shown in FIG. 3, transmit processor 220a includes a TX diversity processor 320 and N_T OFDM modulators. Each OFDM modulator includes an inverse fast Fourier transform (IFFT) unit 330 and a cyclic prefix generator 332. TX diversity processor 320 receives and processes the modulation symbols from TX data processor 210a in accordance with one or more selected transmission modes to provide transmit symbols.

[1057] In an embodiment, TX diversity processor 320 further receives and multiplexes pilot symbols (i.e., pilot data) with the transmit symbols using frequency division multiplexing (FDM) in a subset of the available subbands. An example implementation of an FDM pilot transmission scheme is shown in Table 2. In this implementation, 64 subbands are available for the MIMO OFDM system, and subband indices ±7 and ±21 are used for pilot transmission. In alternative embodiments, the pilot symbols may be multiplexed with the transmit symbols using, for example, time

division multiplexing (TDM), code division multiplexing (CDM), or any combination of FDM, TDM, and CDM.

[1058] TX diversity processor 320 provides one transmit symbol stream to each OFDM modulator. The processing by TX diversity processor 320 is described in further detail below.

[1059] Each OFDM modulator receives a respective transmit symbol stream $x_j(n)$. Within each OFDM modulator, IFFT unit 330 groups each set of N_F transmit symbols in stream $x_j(n)$ to form a corresponding symbol vector, and converts the symbol vector into its time-domain representation (which is referred to as an OFDM symbol) using the inverse fast Fourier transform.

[1060] For each OFDM symbol, cyclic prefix generator 332 repeats a portion of the OFDM symbol to form a corresponding transmission symbol. The cyclic prefix ensures that the transmission symbol retains its orthogonal property in the presence of multipath delay spread, thereby improving performance against deleterious path effects such as channel dispersion caused by frequency selective fading. A fixed or an adjustable cyclic prefix may be used for each OFDM symbol. As a specific example of an adjustable cyclic prefix, a system may have a bandwidth of 20 MHz, a chip period of 50 nsec, and 64 subbands. For this system, each OFDM symbol would have a duration of 3.2 μsec (or 64×50 nsec). The cyclic prefix for each OFDM symbol may have a minimum length of 4 chips (200 nsec) and a maximum length of 16 chips (800 nsec), with an increment of 4 chips (200 nsec). Each transmission symbol would then have a duration ranging from 3.4 μsec to 4.0 μsec for cyclic prefixes of 200 nsec to 800 nsec, respectively.

[1061] Cyclic prefix generator 332 in each OFDM modulator provides a stream of transmission symbols to an associated transmitter 222. Each transmitter 222 receives and processes a respective transmission symbol stream to generate a downlink modulated signal, which is then transmitted from the associated antenna 224.

[1062] The coding and modulation for a MIMO OFDM system are described in further detail in the following U.S. patent applications:

- U.S. Patent Application Serial No. 09/993,087, entitled "Multiple-Access Multiple-Input Multiple-Output (MIMO) Communication System," filed November 6, 2001;
- U.S. Patent Application Serial No. 09/854,235, entitled "Method and Apparatus for Processing Data in a Multiple-Input Multiple-Output (MIMO) Communication System Utilizing Channel State Information," filed May 11, 2001;
- U.S. Patent Application Serial Nos. 09/826,481 and 09/956,449, both entitled "Method and Apparatus for Utilizing Channel State Information in a Wireless Communication System," respectively filed March 23, 2001 and September 18, 2001;
- U.S. Patent Application Serial No. 09/776,075, entitled "Coding Scheme for a Wireless Communication System," filed February 1, 2001; and
- U.S. Patent Application Serial No. 09/532,492, entitled "High Efficiency, High Performance Communications System Employing Multi-Carrier Modulation," filed March 30, 2000.

These patent applications are all assigned to the assignee of the present application and incorporated herein by reference.

[1063] The MIMO OFDM system may be designed to support a number of modes of operation for data transmission. These transmission modes include diversity transmission modes, spatial multiplexing transmission modes, and beam steering transmission modes.

[1064] The spatial multiplexing and beam steering modes may be used to achieve higher bit rates under certain favorable channel conditions. These transmission modes are described in further detail in U.S. Patent Application Serial No. 10/085,456, entitled "Multiple-Input, Multiple-Output (MIMO) Systems with Multiple Transmission Modes," filed February 26, 2002, assigned to the assignee of the present application and incorporated herein by reference.

[1065] The diversity transmission modes may be used to achieve higher reliability for certain data transmissions. For example, the diversity transmission modes may be used for overhead channels on the downlink, such as broadcast, paging, and other common channels. The diversity transmission modes may also be used for data

transmission (1) whenever the transmitter does not have adequate channel state information (CSI) for the communication channel, (2) when the channel conditions are sufficiently poor (e.g., under certain mobility conditions) and cannot support more spectrally efficient transmission modes, and (3) for other situations. When the diversity transmission modes are used for downlink data transmission to the terminals, the rate and/or power for each terminal may be controlled to improve performance. A number of diversity transmission modes may be supported and are described in further detail below.

[1066] The diversity transmission modes attempt to achieve transmit diversity by establishing orthogonality among the multiple signals transmitted from multiple transmit antennas. Orthogonality among the transmitted signals may be attained in frequency, time, space, or any combination thereof. Transmit diversity may be established via any one or combination of the following processing techniques:

- Frequency (or subband) diversity. The inherent orthogonality among the subbands provided by OFDM is used to provide diversity against frequency selective fading.

- Transmit diversity using orthogonal functions. Walsh functions or some other orthogonal functions are applied to OFDM symbols transmitted from multiple transmit antennas to establish orthogonality among the transmitted signals. This scheme is also referred to herein as the "Walsh diversity" scheme.

- Space time transmit diversity (STTD). Spatial orthogonality is established between pairs of transmit antennas while preserving the potential for high spectral efficiency offered by MIMO techniques.

[1067] In general, the frequency diversity scheme may be used to combat frequency selective fading and operates in the frequency and spatial dimensions. The Walsh diversity scheme and STTD scheme operate in the time and spatial dimensions.

[1068] For clarity, the processing techniques enumerated above and certain combinations thereof will be described for an example MIMO OFDM system. In this system, each access point is equipped with four antennas to transmit and receive data, and each terminal may be equipped with one or multiple antennas.

Frequency Diversity

[1069] **FIG. 4** is a block diagram of an embodiment of a TX diversity processor 320a that may be used to implement the frequency diversity scheme. For OFDM, the subbands are inherently orthogonal to one another. Frequency diversity may be established by transmitting identical modulation symbols on multiple subbands.

[1070] As shown in FIG. 4, the modulation symbols, $s(n)$, from TX data processor 210 are provided to a symbol repetition unit 410. Unit 410 repeats each modulation symbol based on the (e.g., dual or quad) diversity to be provided for the modulation symbol. A demultiplexer 412 then receives the repeated symbols and pilot symbols and demultiplexes these symbols into N_T transmit symbol streams. The modulation symbols for each data stream may be transmitted on a respective group of one or more subbands assigned to that data stream. Some of the available subbands may be reserved for pilot transmission (e.g., using FDM). Alternatively, the pilot symbols may be transmitted along with the modulation symbols using TDM or CDM.

[1071] In general, it is desirable to transmit repeated symbols in subbands that are separated from each other by at least the coherence bandwidth of the communication channel. Moreover, the modulation symbols may be repeated over any number of subbands. A higher repetition factor corresponds to greater redundancy and improved likelihood of correct reception at the receiver at the expense of reduced efficiency.

[1072] For clarity, a specific implementation of the frequency diversity scheme is described below for a specific MIMO OFDM system that has some of the characteristics defined by the IEEE Standard 802.11a. The specifications for this IEEE standard are described in a document entitled "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band," September 1999, which is publicly available and incorporated herein by reference. This system has an OFDM waveform structure with 64 subbands. Of these 64 subbands, 48 subbands (with indices of $\pm\{1, \ldots, 6, 8, \ldots, 20, 22, \ldots, 26\}$) are used for data, 4 subbands (with indices of $\pm\{7, 21\}$) are used for pilot, the DC subband (with index of 0) is not used, and the remaining subbands are also not used and serve as guard subbands.

[1073] Table 2 shows a specific implementation for dual and quad frequency diversity for the system described above. For dual frequency diversity, each modulation

symbol is transmitted over two subbands that are separated by either 26 or 27 subbands. For quad frequency diversity, each modulation symbol is transmitted over four subbands that are separated by 13 or 14 subbands. Other frequency diversity schemes may also be implemented and are within the scope of the invention.

Table 2

Subband Indices	Dual Diversity	Quad Diversity	Subband Indices	Dual Diversity	Quad Diversity
-26	1	1	1	1	1
-25	2	2	2	2	2
-24	3	3	3	3	3
-23	4	4	4	4	4
-22	5	5	5	5	5
-21	pilot	pilot	6	6	6
-20	6	6	7	pilot	pilot
-19	7	7	8	7	7
-18	8	8	9	8	8
-17	9	9	10	9	9
-16	10	10	11	10	10
-15	11	11	12	11	11
-14	12	12	13	12	12
-13	13	1	14	13	1
-12	14	2	15	14	2
-11	15	3	16	15	3
-10	16	4	17	16	4
-9	17	5	18	17	5
-8	18	6	19	18	6
-7	pilot	pilot	20	19	7
-6	19	7	21	pilot	pilot
-5	20	8	22	21	8
-4	21	9	23	22	9
-3	22	10	24	23	10
-2	23	11	25	24	11
-1	24	12	26	25	12
0	DC	DC	-	-	-

[1074] The frequency diversity scheme may be used by a transmitter (e.g., a terminal) not equipped with multiple transmit antennas. In this case, one transmit symbol stream is provided by TX diversity processor 310a. Each modulation symbol in $s(n)$ may be repeated and transmitted on multiple subbands. For single-antenna terminals, frequency diversity may be used to provide robust performance in the presence of frequency selective fading.

[1075] The frequency diversity scheme may also be used when multiple transmit antennas are available. This may be achieved by transmitting the same modulation symbol from all transmit antennas on distinct subbands or subband groups. For example, in a four transmit antenna device, every fourth subband may be assigned to one of the transmit antennas. Each transmit antenna would then be associated with a different group of $N_F/4$ subbands. For quad frequency diversity, each modulation symbol would then be transmitted on a set of four subbands, one in each of the four subband groups, with each group being associated with a specific transmit antenna. The four subbands in the set may also be selected such that they are spaced as far apart as possible. For dual frequency diversity, each modulation may be transmitted on a set of two subbands, one in each of two subband groups. Other implementations for frequency diversity with multiple transmit antennas may also be contemplated, and this is within the scope of the invention. The frequency diversity scheme may also be used in combination with one or more other transmit diversity schemes, as described below.

Walsh Transmit Diversity

[1076] **FIG. 5** is a block diagram of an embodiment of a TX diversity processor 320b that may be used to implement the Walsh diversity scheme. For this diversity scheme, orthogonal functions (or codes) are used to establish time orthogonality, which may in turn be used to establish full transmit diversity across all transmit antennas. This is achieved by repeating the same modulation symbols across the transmit antennas, and time spreading these symbols with a different orthogonal function for each transmit antenna, as described below. In general, various orthogonal functions may be used such as Walsh functions, orthogonal variable spreading factor (OVSF) codes, and so on. For clarity, Walsh functions are used in the following description.

[1077] In the embodiment shown in FIG. 5, the modulation symbols, $s(n)$, from TX data processor 210 are provided to a demultiplexer 510, which demultiplexes the symbols into N_B modulation symbol substreams, one substream for each subband used for data transmission (i.e., each data-carrying subband). Each modulation symbol substream $s_k(n)$ is provided to a respective TX subband processor 520.

[1078] Within each TX subband processor 520, the modulation symbols in substream $s_k(n)$ are provided to N_T multipliers 524a through 524d for the N_T transmit antennas (where $N_T = 4$ for this example system). In the embodiment shown in FIG. 5, one modulation symbol s_k is provided to all four multipliers 524 for each 4-symbol period, which corresponds to a symbol rate of $(4T_{OFDM})^{-1}$. Each multiplier also receives a different Walsh function having four chips (i.e., $W_j^4 = \{w_{1j},\ w_{2j},\ w_{3j},\ w_{4j}\}$) and assigned to transmit antenna j associated with that multiplier. Each multiplier then multiplies the symbol s_k with the Walsh function W_j^4 and provides a sequence of four transmit symbols, $\{(s_k \cdot w_{1j}),\ (s_k \cdot w_{2j}),\ (s_k \cdot w_{3j}),\text{ and } (s_k \cdot w_{4j})\}$, which is to be transmitted in four consecutive OFDM symbol periods on subband k of transmit antenna j. These four transmit symbols have the same magnitude as the original modulation symbol s_k. However, the sign of each transmit symbol in the sequence is determined by the sign of the Walsh chip used to generate that transmit symbol. The Walsh function is thus used to time-spread each modulation symbol over four symbol periods. The four multipliers 524a through 524d of each TX subband processor 520 provide four transmit symbol substreams to four buffers/multiplexers 530a through 530d, respectively.

[1079] Each buffer/multiplexer 530 receives pilot symbols and N_B transmit symbol substreams for N_B subbands from N_B TX subband processors 520a through 520f. Each unit 530 then multiplexes the transmit symbols and pilot symbols for each symbol period, and provides a stream of transmit symbols $x_j(n)$ to a corresponding IFFT unit 330. Each IFFT unit 330 receives and processes a respective transmit symbol stream $x_j(n)$ in the manner described above.

[1080] In the embodiment shown in FIG. 5, one modulation symbol is transmitted from all four transmit antennas on each of the N_B data-carrying subbands for each 4-

symbol period. When four transmit antennas are used for data transmission, the spectral efficiency achieved with the Walsh diversity scheme is identical to that achieved with the quad frequency diversity scheme whereby one modulation symbol is transmitted over four data-carrying subbands for each symbol period. In the Walsh diversity scheme with four transmit antennas, the duration or length of the Walsh functions is four OFDM symbols (as designated by the superscript in W_j^4). Since the information in each modulation symbol is distributed over four successive OFDM symbols, the demodulation at the receiver is performed based on four consecutive received OFDM symbols.

[1081] In an alternative embodiment, increased spectral efficiency may be achieved by transmitting distinct modulation symbols (instead of the same modulation symbol) on each transmit antenna. For example, demultiplexer 510 may be designed to provide four distinct modulation symbols, s_1, s_2, s_3, and s_4, to multipliers 524a through 524d for each 4-symbol period. Each multiplier 524 would then multiply a different modulation symbol with its Walsh function to provide a different sequence of four transmit symbols. The spectral efficiency for this embodiment would then be four times that of the embodiment shown in FIG. 5. As another example, demultiplexer 510 may be designed to provide two distinct modulation symbols (e.g., s_1 to multipliers 524a and 524b and s_2 to multipliers 524c and 524d) for each 4-symbol period.

<u>Space-Time Transmit Diversity (STTD)</u>

[1082] Space-time transmit diversity (STTD) supports simultaneous transmission of effectively two independent symbol streams on two transmit antennas while maintaining orthogonality at the receiver. An STTD scheme may thus provide higher spectral efficiency over the Walsh transmit diversity scheme shown in FIG. 5.

[1083] The STTD scheme operates as follows. Suppose that two modulation symbols, denoted as s_1 and s_2, are to be transmitted on a given subband. The transmitter generates two vectors, $\underline{\mathbf{x}}_1 = [s_1 \;\; s_2^*]^T$ and $\underline{\mathbf{x}}_2 = [s_2 \;\; -s_1^*]^T$. Each vector includes two elements that are to be transmitted sequentially in two symbol periods from a respective transmit antenna (i.e., vector $\underline{\mathbf{x}}_1$ is transmitted from antenna 1 and vector $\underline{\mathbf{x}}_2$ is transmitted from antenna 2).

[1084] If the receiver includes a single receive antenna, then the received signal may be expressed in matrix form as:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_1 s_1 + h_2 s_2 \\ h_1 s_2^* - h_2 s_1^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} , \qquad \text{Eq (1)}$$

where r_1 and r_2 are two symbols received in two consecutive symbol periods at the receiver;

h_1 and h_2 are the path gains from the two transmit antennas to the receive antenna for the subband under consideration, where the path gains are assumed to be constant over the subband and static over the 2-symbol period; and

n_1 and n_2 are the noise associated with the two received symbols r_1 and r_2.

[1085] The receiver may then derive estimates of the two transmitted symbols, s_1 and s_2, as follows:

$$\hat{s}_1 = h_1^* r_1 - h_2 r_2^* = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 - h_2 n_2 \text{ , and} \qquad \text{Eq (2)}$$

$$\hat{s}_2 = h_2^* r_1 + h_1 r_2^* = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n_1 + h_1 n_2 \text{ .}$$

[1086] In an alternative implementation, the transmitter may generate two vectors, $\underline{\mathbf{x}}_1 = [s_1 \;\; s_2]^T$ and $\underline{\mathbf{x}}_2 = [-s_2^* \;\; s_1^*]^T$, with the elements of these two vectors being transmitted sequentially in two symbol periods from the two transmit antennas. The received signal may then be expressed as:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_1 s_1 - h_2 s_2^* \\ h_1 s_2 + h_2 s_1^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} .$$

The receiver may then derive estimates of the two transmitted symbols as follows:

$$\hat{s}_1 = h_1^* r_1 + h_2 r_2^* = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2 n_2 \text{ , and}$$

$$\hat{s}_2 = -h_2 r_1^* + h_1^* r_2 = (|h_1|^2 + |h_2|^2) s_2 - h_2 n_1 + h_1^* n_2 \text{ .}$$

[1087] When two transmit antennas are employed for data transmission, the STTD scheme is twice as spectrally efficient as both the dual frequency diversity scheme and the Walsh diversity scheme with two transmit antennas. The STTD scheme effectively transmits one independent modulation symbol per subband over the two transmit antennas in each symbol period, whereas the dual frequency diversity scheme transmits only a single modulation symbol per two subbands in each symbol period and the Walsh diversity scheme transmits only a single modulation symbol on each subband in two symbol periods. Since the information in each modulation symbol is distributed over two successive OFDM symbols for the STTD scheme, the demodulation at the receiver is performed based on two consecutive received OFDM symbols.

[1088] **FIG. 6** is a block diagram of an embodiment of a TX diversity processor 320c that may be used to implement the STTD scheme. In this embodiment, the modulation symbols, $s(n)$, from TX data processor 210 are provided to a demultiplexer 610, which demultiplexes the symbols into $2N_B$ modulation symbol substreams, two substreams for each data-carrying subband. Each pair of modulation symbol substreams is provided to a respective TX subband processor 620. Each modulation symbol substream includes one modulation symbol for each 2-symbol period, which corresponds to a symbol rate of $(2T_{OFDM})^{-1}$.

[1089] Within each TX subband processor 620, the pair of modulation symbol substreams is provided to a space-time encoder 622. For each pair of modulation symbols in the two substreams, space-time encoder 622 provides two vectors, $\underline{\mathbf{x}}_1 = [s_1 \;\; s_2^*]^T$ and $\underline{\mathbf{x}}_2 = [s_2 \;\; -s_1^*]^T$, with each vector including two transmit symbols to be transmitted in two symbol periods. The two transmit symbols in each vector have the same magnitude as the original modulation symbols, s_1 and s_2. However, each transmit symbol may be rotated in phase relative to the original modulation symbol. Each TX subband processor 620 thus provides two transmit symbol substreams to two buffers/multiplexers 630a and 630b, respectively.

[1090] Each buffer/multiplexer 630 receives pilot symbols and N_B transmit symbol substreams from N_B TX subband processors 620a through 620f, multiplexes the transmit symbols and pilot symbols for each symbol period, and provides a stream of transmit

symbols $x_j(n)$ to a corresponding IFFT unit 330. Each IFFT unit 330 then processes a respective transmit symbol stream in the manner described above.

[1091] The STTD scheme is described in further detail by S.M. Alamouti in a paper entitled "A Simple Transmit Diversity Technique for Wireless Communications," IEEE Journal on Selected Areas in Communications, Vol. 16, No. 8, October 1998, pgs. 1451-1458, which is incorporated herein by reference. The STTD scheme is also described in further detail in U.S. Patent Application Serial No. 09/737,602, entitled "Method and System for Increased Bandwidth Efficiency in Multiple Input - Multiple Output Channels," filed January 5, 2001, assigned to the assignee of the present application and incorporated herein by reference.

Walsh-STTD

[1092] A Walsh-STTD scheme employs a combination of Walsh diversity and STTD described above. The Walsh-STTD scheme may be used in systems with more than two transmit antennas. For a Walsh-STTD with repeated symbols scheme (which is also referred to as the repeated Walsh-STTD scheme), two transmit vectors $\underline{\mathbf{x}}_1$ and $\underline{\mathbf{x}}_2$ are generated for each pair of modulation symbols to be transmitted on a given subband from two transmit antennas, as described above for FIG. 6. These two transmit vectors are also repeated across multiple pairs of transmit antennas using Walsh functions to achieve orthogonality across the transmit antenna pairs and to provide additional transmit diversity.

[1093] **FIG. 7** is a block diagram of an embodiment of a TX diversity processor 320d that may be used to implement the repeated Walsh-STTD scheme. The modulation symbols, $s(n)$, from TX data processor 210 are provided to a demultiplexer 710, which demultiplexes the symbols into $2N_B$ modulation symbol substreams, two substreams for each data-carrying subband. Each modulation symbol substream includes one modulation symbol for each 4-symbol period, which corresponds to a symbol rate of $(4T_{OFDM})^{-1}$. Each pair of modulation symbol substreams is provided to a respective TX subband processor 720.

[1094] A space-time encoder 722 within each TX subband processor 720 receives the pair of modulation symbol substreams and, for each 4-symbol period, forms a pair

of modulation symbols $\{s_1$ and $s_2\}$, with one symbol coming from each of the two substreams. The pair of modulation symbols $\{s_1$ and $s_2\}$ is then used to form two vectors, $\underline{\mathbf{x}}_1 = [s_1 \;\; s_2^*]^T$ and $\underline{\mathbf{x}}_2 = [s_2 \;\; -s_1^*]^T$, with each vector spanning a 4-symbol period. Space-time encoder 722 provides the first vector $\underline{\mathbf{x}}_1$ to multipliers 724a and 724c and the second vector $\underline{\mathbf{x}}_2$ to multipliers 724b and 724d. Multipliers 724a and 724b each also receive a Walsh function having two chips (i.e., $W_1^2 = \{w_{11}, \; w_{21}\}$) and assigned to transmit antennas 1 and 2. Similarly, multipliers 724c and 724d each also receive a Walsh function W_2^2 having two chips and assigned to transmit antennas 3 and 4. Each multiplier 724 then multiplies each symbol in its vector $\underline{\mathbf{x}}_j$ with its Walsh function to provide two transmit symbols to be transmitted in two consecutive symbol periods on subband *k* of transmit antenna *j*.

[1095] In particular, multiplier 724a multiplies each symbol in vector $\underline{\mathbf{x}}_1$ with the Walsh function W_1^2 and provides a sequence of four transmit symbols, $\{(s_1 \cdot w_{11}),\ (s_1 \cdot w_{21}),\ (s_2^* \cdot w_{11}),$ and $(s_2^* \cdot w_{21})\}$, which is to be transmitted in four consecutive symbol periods. Multiplier 724b multiplies each symbol in vector $\underline{\mathbf{x}}_2$ with the Walsh function W_1^2 and provides a sequence of four transmit symbols, $\{(s_2 \cdot w_{11}),\ (s_2 \cdot w_{21}),\ (-s_1^* \cdot w_{11}),$ and $(-s_1^* \cdot w_{21})\}$. Multiplier 724c multiplies each symbol in vector $\underline{\mathbf{x}}_1$ with the Walsh function W_2^2 and provides a sequence of four transmit symbols, $\{(s_1 \cdot w_{12}),\ (s_1 \cdot w_{22}),\ (s_2^* \cdot w_{12}),$ and $(s_2^* \cdot w_{22})\}$. And multiplier 724d multiplies each symbol in vector $\underline{\mathbf{x}}_2$ with the Walsh function W_2^2 and provides a sequence of four transmit symbols, $\{(s_2 \cdot w_{12}),\ (s_2 \cdot w_{22}),\ (-s_1^* \cdot w_{12}),$ and $(-s_1^* \cdot w_{22})\}$. The Walsh function is thus used to time-spread each symbol or element in the vector $\underline{\mathbf{x}}$ over two symbol periods. The four multipliers 724a through 724d of each TX subband processor 720 provide four transmit symbol substreams to four buffers/multiplexers 730a through 730d, respectively.

[1096] Each buffer/multiplexer 730 receives pilot symbols and N_B transmit symbol substreams from N_B TX subband processors 720a through 720f, multiplexes the pilot and transmit symbols for each symbol period, and provides a stream of transmit

symbols $x_j(n)$ to a corresponding IFFT unit 330. The subsequent processing is as described above.

[1097] The repeated Walsh-STTD scheme shown in FIG. 7 (with four transmit antennas) has the same spectral efficiency as the STTD scheme shown in FIG. 6 and twice the spectral efficiency of the Walsh diversity scheme shown in FIG. 5. However, additional diversity is provided by this Walsh-STTD scheme by transmitting repeated symbols over multiple pairs of transmit antennas. The Walsh-STTD processing provides full transmit diversity (per subband) for the signals transmitted from all transmit antennas.

[1098] **FIG. 8** is a block diagram of an embodiment of a TX diversity processor 320e that may be used to implement a Walsh-STTD without repeated symbols scheme (which is also referred to as the non-repeated Walsh-STTD scheme). This scheme may be used to increase spectral efficiency at the expense of less diversity than the scheme shown in FIG. 7. As shown in FIG. 8, the modulation symbols $s(n)$ are provided to a demultiplexer 810, which demultiplexes the symbols into $4N_B$ modulation symbol substreams, four substreams for each data-carrying subband. Each set of four modulation symbol substreams is provided to a respective TX subband processor 820.

[1099] Within each TX subband processor 820, a space-time encoder 822a receives the first pair of modulation symbol substreams and a space-time encoder 822b receives the second pair of modulation symbol substreams. For each pair of modulation symbols in the two substreams in the first pair, space-time encoder 822a provides two vectors $\underline{\mathbf{x}}_1 = [s_1 \;\; s_2^*]^T$ and $\underline{\mathbf{x}}_2 = [s_2 \;\; -s_1^*]^T$ to multipliers 824a and 824b, respectively. Similarly, for each pair of modulation symbols in the two substreams in the second pair, space-time encoder 822b provides two vectors $\underline{\mathbf{x}}_3 = [s_3 \;\; s_4^*]^T$ and $\underline{\mathbf{x}}_4 = [s_4 \;\; -s_3^*]^T$ to multipliers 824c and 824d, respectively

[1100] Multipliers 824a and 824b each also receive Walsh function W_1^2, and multipliers 824c and 824d each also receive Walsh function W_2^2. Each multiplier 824 then multiplies each symbol in its vector $\underline{\mathbf{x}}_j$ with its Walsh function to provide two transmit symbols to be transmitted in two consecutive symbol periods on subband k of transmit antenna j. The four multipliers 824a through 824d of each TX subband

processor 820 provide four transmit symbol substreams to four buffers/multiplexers 830a through 830d, respectively.

[1101] Each buffer/multiplexer 830 receives pilot symbols and N_B transmit symbol substreams from N_B TX subband processors 820a through 820f, multiplexes the pilot symbols and transmit symbols for each symbol period, and provides a stream of transmit symbols $x_j(n)$ to a corresponding IFFT unit 330. The subsequent processing is as described above.

[1102] The non-repeated Walsh-STTD scheme shown in FIG. 8 (with four transmit antennas) has twice the spectral efficiency as the repeated Walsh-STTD scheme shown in FIG. 7. The same processing may be extended to a system with any number of transmit antenna pairs. Instead of repeating the two transmit vectors across the pairs of transmit antennas, each transmit antenna pair may be used to transmit independent symbol streams. This results in greater spectral efficiency at the possible expense of diversity performance. Some of this diversity may be recovered by the use of forward error correction (FEC) code.

[1103] The Walsh-STTD scheme is also described in further detail in the aforementioned U.S. Patent Application Serial No. 09/737,602.

Frequency-STTD

[1104] A frequency-STTD scheme employs a combination of frequency diversity and STTD. The frequency-STTD scheme may also employ antenna diversity for systems with more than one pair of transmit antennas. For the frequency-STTD scheme, each modulation symbol is transmitted on multiple (e.g., two) subbands and provided to multiple TX subband processors. The subbands to be used for each modulation symbol may be selected such that they are spaced as far apart as possible (e.g., as shown in Table 1) or based on some other subband assignment scheme. If four transmit antennas are available, then for each subband two pairs of modulation symbols are processed using STTD. The first pair of modulation symbols is transmitted from the first pair of antennas (e.g., transmit antennas 1 and 2), and the second pair of modulation symbols is transmitted from the second pair of antennas (e.g., transmit antennas 3 and 4).

[1105] Each modulation symbol is thus transmitted on multiple subbands and over multiple transmit antennas. For clarity, the processing for a given modulation symbol s_a for a system with four transmit antennas and using dual frequency diversity may be performed as follows. Modulation symbol s_a is initially provided to two TX subband processors (e.g., for subbands k and $k + N_F / 2$). In subband k, modulation symbol s_a is processed with another modulation symbol s_b using STTD to form two vectors, $\underline{\mathbf{x}}_1 = [s_a \;\; s_b^*]^T$ and $\underline{\mathbf{x}}_2 = [s_b \;\; -s_a^*]^T$, which are transmitted from transmit antennas 1 and 2, respectively. In subband $k + N_F / 2$, modulation symbol s_a is processed with another modulation symbol s_c using STTD to form two vectors, $\underline{\mathbf{x}}_3 = [s_a \;\; s_c^*]^T$ and $\underline{\mathbf{x}}_4 = [s_c \;\; -s_a^*]^T$, which are transmitted from transmit antennas 3 and 4, respectively. Modulation symbol s_c may be the same as modulation symbol s_b or a different modulation symbol.

[1106] For the above implementation of the frequency-STTD scheme, the modulation symbol in each subband has two orders of transmit diversity provided by the STTD processing. Each modulation symbol to be transmitted has four orders of transmit diversity plus some frequency diversity provided by the use of two subbands and STTD. This frequency-STTD scheme has the same spectral efficiency as the repeated Walsh-STTD scheme. However, the total transmission time for each modulation symbol is two symbol periods with the frequency-STTD scheme, which is half the total transmission time for each modulation symbol with the Walsh-STTD scheme, since Walsh processing is not performed by the frequency-STTD scheme.

[1107] In one embodiment of the frequency-STTD scheme, all subbands are used by each pair of transmit antennas for data transmission. For quad diversity, each modulation symbol is provided to two subbands for two transmit antenna pairs, as described above. In another embodiment of the frequency-STTD scheme, each pair of transmit antennas is assigned a different subband group for data transmission. For example, in a device with two pairs of transmit antennas, every other subband may be assigned to one transmit antenna pair. Each transmit antenna pair would then be associated with a different group of $N_F / 2$ subbands. For quad diversity, each modulation symbol would then be transmitted on two subbands, one in each of the two

subband groups, with each group being associated with a specific transmit antenna pair. The two subbands used for each modulation symbol may be selected such that they are spaced as far apart as possible. Other implementations for frequency-STTD diversity with multiple transmit antenna pairs may also be contemplated, and this is within the scope of the invention.

[1108] As illustrated by the above, various diversity schemes may be implemented using various processing techniques described herein. For clarity, specific implementations of various diversity schemes have been described above for a specific system. Variations of these diversity schemes may also be implemented, and this is within the scope of the invention.

[1109] Moreover, other diversity schemes may also be implemented based on other combinations of the processing techniques described herein, and this is also within the scope of the invention. For example, another diversity scheme may utilize frequency diversity and Walsh transmit diversity, and yet another diversity scheme may utilize frequency diversity, Walsh diversity, and STTD.

Diversity Transmission Modes

[1110] A number of diversity transmission modes may be implemented using the transmit processing schemes described above. These diversity transmission modes may include the following:

- Frequency diversity transmission mode - employs only frequency diversity (e.g., dual, quad, or some other integer multiple frequency diversity).
- Walsh diversity transmission mode - employs only Walsh transmit diversity.
- STTD transmission mode - employs only STTD.
- Walsh-STTD transmission mode - employs both Walsh transmit diversity and STTD, with repeated or non-repeated symbols.
- Frequency-STTD transmission mode - employs frequency diversity and STTD.
- Frequency-Walsh transmission mode - employs frequency diversity and Walsh transmit diversity.

- Frequency-Walsh-STTD transmission mode - employs frequency diversity. Walsh transmit diversity, and STTD.

[1111] The diversity transmission modes may be used for data transmission between the access points and terminals. The specific transmission mode to use for a given data stream may be dependent on various factors such as (1) the type of data being transmitted (e.g., whether common for all terminals or user-specific for a particular terminal), (2) the number of antennas available at the transmitter and receiver, (3) the channel conditions, (4) the requirements of the data transmission (e.g., the required packet error rate), and so on.

[1112] Each access point in the system may be equipped with, for example, four antennas for data transmission and reception. Each terminal may be equipped with one, two, four, or some other number of antennas for data transmission and reception. Default diversity transmission modes may be defined and used for each terminal type. In a specific embodiment, the following diversity transmission modes are used as default:

- Single-antenna terminals – use frequency diversity transmission mode with dual or quad diversity.
- Dual-antenna terminals – use STTD transmission mode for dual diversity and frequency-STTD transmission mode for quad diversity.
- Quad-antenna terminals – use STTD transmission mode for dual diversity and Walsh-STTD transmission mode for quad diversity.

Other diversity transmission modes may also be selected as the default modes, and this is within the scope of the invention.

[1113] The diversity transmission modes may also be used to increase the reliability of data transmission on overhead channels intended to be received by all terminals in the system. In an embodiment, a specific diversity transmission mode is used for the broadcast channel, and this mode is known *a priori* by all terminals in the system (i.e., no signaling is required to identify the transmission mode used for the broadcast channel). In this way, the terminals are able to process and recover the data transmitted on the broadcast channel. The transmission modes used for other overhead channels may be fixed or dynamically selected. In one dynamic selection scheme, the system

determines which transmission mode is the most reliable (and spectrally efficient) to use for each of the remaining overhead channels based on the mix of terminals being served. The transmission modes selected for use for these overhead channels and other configuration information may be signaled to the terminals, for example, via the broadcast channel.

[1114] With OFDM, the subbands may be treated as distinct transmission channels, and the same or different diversity transmission modes may be used for the subbands. For example, one diversity transmission mode may be used for all data-carrying subbands, or a separate diversity transmission mode may be selected for each data-carrying subband. Moreover, for a given subband, it may be possible to use different diversity transmission modes for different sets of transmit antennas.

[1115] In general, each data stream (whether for an overhead channel or a specific receiver device) may be coded and modulated based on the coding and modulation schemes selected for that data stream to provide modulation symbols. The modulation symbols are then further processed based on the diversity transmission mode selected for that data stream to provide transmit symbols. The transmit symbols are further processed and transmitted on a group of one or more subbands from a set of one or more transmit antennas designated to be used for that data stream.

Receiver Unit

[1116] **FIG. 9** is a block diagram of a receiver unit 900, which is an embodiment of the receiver portion of a multi-antenna terminal 106. The downlink modulated signals from access point 104 are received by antennas 252a through 252r, and the received signal from each antenna is provided to a respective receiver 254. Each receiver 254 processes (e.g., conditions, digitizes, and data demodulates) the received signal to provide a stream of received transmission symbols, which is then provided to a respective OFDM demodulator within a receive processor 260a.

[1117] Each OFDM demodulator includes a cyclic prefix removal unit 912 and a fast Fourier transform (FFT) unit 914. Unit 912 removes the cyclic prefix that had been appended in each transmission symbol to provide a corresponding received OFDM symbol. The cyclic prefix removal may be performed by determining a set of N_A samples corresponding to each received transmission symbol and selecting a subset of

these N_A samples as the set of N_F samples for the received OFDM symbol. FFT 914 then transforms each received OFDM symbol (or each set of N_F samples) using the fast Fourier transform to provide a vector of N_F received symbols for the N_F subbands. FFT units 914a through 914r provide N_R received symbol streams, $r_1(n)$ through $r_{N_R}(n)$, to an RX diversity processor 920.

[1118] RX diversity processor 920 performs diversity processing on the N_R received symbol streams to provide recovered symbols, $\hat{s}(n)$, which are estimates of the modulation symbols, $s(n)$, sent by the transmitter. The processing to be performed by RX diversity processor 920 is dependent on the transmission mode used for each data stream to be recovered, as indicated by the transmission mode control. RX diversity processor 920 is described in further detail below.

[1119] RX diversity processor 920 provides the recovered symbols, $\hat{s}(n)$, for all data streams to be recovered to an RX data processor 262a, which is an embodiment of RX data processor 262 in FIG. 2. Within processor 262a, a symbol demapping element 942 demodulates the recovered symbols for each data stream in accordance with a demodulation scheme that is complementary to the modulation scheme used for the data stream. A channel deinterleaver 944 then deinterleaves the demodulated data in a manner complementary to the interleaving performed at the transmitter for the data stream, and the deinterleaved data is further decoded by a decoder 946 in a manner complementary to the coding performed at the transmitter. For example, a Turbo decoder or a Viterbi decoder may be used for decoder 946 if Turbo or convolutional coding, respectively, is performed at the transmitter. The decoded data from decoder 946 represents an estimate of the transmitted data being recovered. Decoder 946 may also provide the status of each received packet (e.g., indicating whether it was received correctly or in error).

[1120] In the embodiment shown in FIG. 9, a channel estimator 950 estimates various channel characteristics such as the channel response and the noise variance (e.g., based on recovered pilot symbols) and provides these estimates to controller 270. Controller 270 may be designed to perform various functions related to diversity processing at the receiver. For example, controller 270 may determine the diversity transmission mode used for each data stream to be recovered and may further direct the operation of RX diversity processor 920.

[1121] **FIG. 10** is a block diagram of an embodiment of an RX diversity processor 920x, which may be used for a multi-antenna receiver device. In this embodiment, the N_R received symbol streams for the N_R receive antennas are provided to N_R RX antenna processors 1020a through 1020r. Each RX antenna processor 1020 processes a respective received symbol stream, $r_i(n)$, and provides a corresponding recovered symbol stream, $\hat{s}_i(n)$, for the associated receive antenna. In an alternative embodiment, one or more RX antenna processors 1020 are time shared and used to process all N_R received symbol streams.

[1122] A combiner 1030 then receives and combines the N_R recovered symbol streams from the N_R RX antenna processors 1020a through 1020r to provide a single recovered symbol stream, $\hat{s}(n)$. The combining may be performed on a symbol-by-symbol basis. In an embodiment, for a given subband k, the N_R recovered symbols from the N_R receive antennas for each symbol period (which are denoted as $\{\hat{s}_{ki}\}$, for $i = (1, 2, \dots, N_R)$) are initially scaled by N_R weights assigned to the N_R receive antennas. The N_R scaled symbols are then summed to provide the recovered symbol, $\hat{s}_k$, for subband k. The weights may be selected to achieve maximal-ratio combining, and may be determined based on the signal quality (e.g., SNR) associated with the receive antennas. The scaling with the weights may also be performed via an automatic gain control (AGC) loop maintained for each receive antenna, as is known in the art.

[1123] For a single-antenna receiver device, there is only one received symbol stream. In this case, only one RX antenna processor 1020 is needed. A design for RX antenna processor 1020 is described in further detail below.

[1124] The recovered symbol steam, $\hat{s}(n)$, provided by combiner 1030 may include the recovered symbols for all data streams transmitted by the transmitter. Alternatively, the steam $\hat{s}(n)$ may include only the recovered symbols for one or more data streams to be recovered by the receiver device.

[1125] **FIG. 11** is a block diagram of an RX antenna processor 1020x that may be used to perform the receive processing for the Walsh diversity scheme shown in FIG. 5. RX antenna processor 1020x processes the received symbol stream $r_i(n)$ for one receive antenna and may be used for each of RX antenna processors 1020a through 1020r in FIG. 10.

[1126] In the embodiment shown in FIG. 11, the received symbol stream $r_i(n)$ is provided to a demultiplexer 1110, which demultiplexes the received symbols in $r_i(n)$ into N_B substreams of received symbols (which are denoted as r_1 through r_{N_B}, where the index i has been dropped for simplicity), one substream for each data-carrying subband. Each received symbol substream r_k is then provided to a respective RX subband processor 1120.

[1127] Each RX subband processor 1120 includes a number of receive processing paths, one path for each transmit antenna used for data transmission (four receive processing paths are shown in FIG. 11 for four transmit antennas). For each processing path, the received symbols in the substream are provided to a multiplier 1122 that also receives a scaled Walsh function $\hat{h}^*_{kj}(W^4_j)^*$, where $\hat{h}^*_{kj}$ is the complex-conjugated channel response estimate between transmit antenna j (which is associated with that multiplier) and the receive antenna for subband k, and $(W^4_j)^*$ is the complex-conjugated Walsh function assigned to transmit antenna j. Each multiplier 1122 then multiplies the received symbols with the scaled Walsh function and provides the results to an associated integrator 1124. Integrator 1124 then integrates the multiplier results over the length of the Walsh function (or four symbol periods) and provides the integrated output to a summer 1126. One received symbol is provided to multiplier 1122 for each symbol period (i.e., rate $= (\mathrm{T_{OFDM}})^{-1}$) and integrator 1124 provides one integrated output for each 4-symbol period (i.e., rate $= (4\mathrm{T_{OFDM}})^{-1}$).

[1128] For each 4-symbol period, summer 1126 combines the four outputs from integrators 1124a through 1124d to provide a recovered symbol, $\hat{s}_k$, for subband k, which is an estimate of the modulation symbol, s_k, transmitted in that subband. For each 4-symbol period, RX subband processors 1120a through 1120f provide N_B recovered symbols, $\hat{s}_1$ through $\hat{s}_{N_B}$, for the N_B data-carrying subbands.

[1129] A multiplexer 1140 receives the recovered symbols from RX subband processors 1120a through 1120f and multiplexes these symbols into a recovered symbol stream, $\hat{s}_i(n)$, for receive antenna i.

[1130] **FIG. 12** is a block diagram of an RX subband processor 1120x that may be used to perform the receive processing for the Walsh-STTD schemes shown in FIGS. 7

and 8. RX subband processor 1120x processes one received symbol substream r_k for one subband of one receive antenna and may be used for each of RX subband processors 1120a through 1120f in FIG. 11.

[1131] In the embodiment shown in FIG. 12, the received symbols in substream r_k are provided to two receive processing paths, one path for each transmit antenna pair used for data transmission (two receive processing paths are shown in FIG. 12 for four transmit antennas). For each processing path, the received symbols are provided to a multiplier 1222 that also receives a complex-conjugated Walsh function $(W_j^2)^*$ assigned to the transmit antenna pair being processed by that path. Each multiplier 1222 then multiplies the received symbols with the Walsh function and provides the results to an associated integrator 1224. Integrator 1224 then integrates the multiplier results over the length of the Walsh function (or two symbol periods) and provides the integrated output to a delay element 1226 and a unit 1228. One received symbol is provided to multiplier 1222 for each symbol period (i.e., rate $= (\mathrm{T}_{\mathrm{OFDM}})^{-1}$) and integrator 1224 provides one integrated output for each 2-symbol period (i.e., rate $= (2\mathrm{T}_{\mathrm{OFDM}})^{-1}$).

[1132] Referring back to FIG. 8, for the non-repeated Walsh-STTD scheme, four modulation symbols $\{s_{k1},\ s_{k2},\ s_{k3},$ and $s_{k4}\}$ are transmitted over two transmit antenna pairs in four symbol periods for subband k (where the index k is used to denote subband k). The symbol pair $\{s_{k1}$ and $s_{k2}\}$ is transmitted over the first transmit antenna pair, and the symbol pair $\{s_{k3}$ and $s_{k4}\}$ is transmitted over the second transmit antenna pair. Each modulation symbol is transmitted in two symbol periods using the 2-chip Walsh function assigned to the transmit antenna pair.

[1133] Referring back to FIG. 12, the complementary processing is performed at the receiver to recover the modulation symbols. For each 4-symbol period corresponding to a new symbol pair transmitted from each transmit antenna pair for subband k, integrator 1224 provides a received symbol pair $\{r_{k1}$ and $r_{k2}\}$. Delay element 1226 then provides a delay of two symbol periods (i.e., $\mathrm{T}_{\mathrm{W}} = 2\mathrm{T}_{\mathrm{OFDM}}$, which is the length of the Walsh function) for the first symbol (i.e., r_{k1}) in the pair, and unit 1228 provides the complex-conjugate of the second symbol (i.e., r_{k2}^*) in the pair.

[1134] Multipliers 1230a through 1230d and summers 1232a and 1232b then collectively perform the computations shown in equation (2) for the first transmit antenna pair. In particular, multiplier 1230a multiplies the symbol r_{k1} with the channel response estimate $\hat{h}^*_{k1}$, multiplier 1230b multiplies the symbol r^*_{k2} with the channel response estimate $\hat{h}_{k2}$, multiplier 1230c multiplies the symbol r_{k1} with the channel response estimate $\hat{h}^*_{k2}$, and multiplier 1230d multiplies the symbol r^*_{k2} with the channel response estimate $\hat{h}_{k1}$, where $\hat{h}_{kj}$ is an estimate of the channel response from transmit antenna *j* to the receive antenna for subband *k*. Summer 1232a then subtracts the output of multiplier 1230b from the output of multiplier 1230a to provide an estimate, $\hat{s}_{k1}$, of the first modulation symbol in the pair $\{s_{k1}$ and $s_{k2}\}$. Summer 1232b adds the output of multiplier 1230c with the output of multiplier 1230d to provide an estimate, $\hat{s}_{k2}$, of the second modulation symbol in the pair.

[1135] The processing by the second path for the second transmit antenna pair is similar to that described above for the first path. However, the channel response estimates, $\hat{h}_{k3}$ and $\hat{h}_{k4}$, for the second pair of transmit antennas for subband *k* are used for the second processing path. For each 4-symbol period, the second processing path provides the symbol estimates $\hat{s}_{k3}$ and $\hat{s}_{k4}$ for the pair of modulation symbols $\{s_{k3}$ and $s_{k4}\}$ transmitted on subband *k* from the second transmit antenna pair.

[1136] For the non-repeated Walsh-STTD scheme shown in FIG. 8, $\hat{s}_{k1}$, $\hat{s}_{k2}$, $\hat{s}_{k3}$, and $\hat{s}_{k4}$ represent the estimates of the four modulation symbols s_{k1}, s_{k2}, s_{k3}, and s_{k4} sent over four transmit antennas on subband *k* in a 4-symbol period. These symbol estimates may then be multiplexed together into a recovered symbol substream, $\hat{s}_k(n)$, for subband *k*, which is then provided to multiplexer 1140 in FIG. 11.

[1137] For the repeated Walsh-STTD scheme shown in FIG. 7, one symbol pair $\{s_{k1}$ and $s_{k2}\}$ is sent over both pairs of transmit antennas on subband *k* in each 4-symbol period. The symbol estimates $\hat{s}_{k1}$ and $\hat{s}_{k3}$ may then be combined by a summer (not shown in FIG. 12) to provide an estimate of the first symbol in the pair, and the

symbol estimates $\hat{s}_{k2}$ and $\hat{s}_{k4}$ may similarly be combined by another summer to provide an estimate of the second symbol in the pair. The symbol estimates from these two summers may then be multiplexed together into a recovered symbol substream, $\hat{s}_k(n)$, for subband k, which is then provided to multiplexer 1140 in FIG. 11.

[1138] For clarity, various details are specifically described for downlink data transmission from an access point to a terminal. The techniques described herein may also be used for the uplink, and this is within the scope of the invention. For example, the processing schemes shown in FIGS. 4, 5, 6, 7, and 8 may be implemented within a multi-antenna terminal for uplink data transmission.

[1139] The MIMO OFDM system described herein may also be designed to implement one or more multiple access schemes such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), and so on. CDMA may provide certain advantages over other types of system, such as increased system capacity. The MIMO OFDM system may also be designed to implement various processing techniques described in CDMA standards such as IS-95, cdma2000, IS-856, W-CDMA, and others.

[1140] The techniques described herein for transmitting and receiving data using a number of diversity transmission modes may be implemented by various means. For example, these techniques may be implemented in hardware, software, or a combination thereof. For a hardware implementation, the elements (e.g., TX diversity processor, RX diversity processor, TX subband processors, RX antenna processors, RX subband processors, and so on) used to implement any one or a combination of the techniques may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof.

[1141] For a software implementation, any one or a combination of the techniques described herein may be implemented with modules (e.g., procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in a memory unit (e.g., memory 232 or 272 in FIG. 2) and executed by a processor (e.g., controller 230 or 270). The memory unit may be implemented within the processor or

external to the processor, in which case it can be communicatively coupled to the processor via various means as it known in the art.

[1142] Headings are included herein for reference and to aid in locating certain sections. These heading are not intended to limit the scope of the concepts described therein under, and these concepts may have applicability in other sections throughout the entire specification.

[1143] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[1144] **WHAT IS CLAIMED IS:**

CLAIMS

1. A method for processing data for transmission in a wireless communication system, comprising:

selecting a particular diversity transmission mode from among a plurality of possible transmission modes to use for each of one or more data streams, wherein each selected diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof;

coding and modulating each data stream based on coding and modulation schemes selected for the data stream to provide modulation symbols; and

processing the modulation symbols for each data stream based on the selected diversity transmission mode to provide transmit symbols for transmission over one or more transmit antennas.

2. The method of claim 1, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode.

3. The method of claim 1, wherein the plurality of possible transmission modes includes a Walsh diversity transmission mode.

4. The method of claim 3, wherein the Walsh diversity transmission mode transmits each modulation symbol over N_T symbol periods, where N_T is the number of transmit antennas used for data transmission.

5. The method of claim 4, wherein the Walsh diversity transmission mode transmits each modulation symbol over all N_T transmit antennas.

6. The method of claim 1, wherein the plurality of possible transmission modes includes a space time transmit diversity (STTD) transmission mode.

7. The method of claim 1, wherein the plurality of possible transmission modes includes a Walsh-STTD transmission mode.

8. The method of claim 1, wherein the plurality of possible transmission modes includes a frequency-STTD transmission mode.

9. The method of claim 7, wherein the Walsh-STTD transmission mode redundantly transmits modulation symbols over a plurality of pairs of transmit antennas.

10. The method of claim 7, wherein the Walsh-STTD transmission mode transmits different modulation symbols over different pairs of transmit antennas.

11. The method of claim 1, wherein the wireless communication system is a multiple-input multiple-output (MIMO) communication system, and wherein the transmit symbols for the one or more data streams are transmitted over a plurality of transmit antennas.

12. The method of claim 11, wherein the MIMO communication system utilizes orthogonal frequency division multiplexing (OFDM).

13. The method of claim 12, further comprising:

OFDM modulating the transmit symbols for the one or more data streams to provide a stream of transmission symbols for each transmit antenna used for data transmission.

14. The method of claim 12, wherein the transmit symbols for each data stream are transmitted on a respective group of one or more subbands.

15. The method of claim 1, wherein at least one data stream is transmitted for an overhead channel.

16. The method of claim 14, wherein the data stream for a broadcast channel is transmitted based on a fixed diversity transmission mode.

17. The method of claim 1, wherein at least one data stream is user-specific and transmitted for a specific receiver device.

18. The method of claim 17, wherein data rate for each of the at least one user-specific data stream is adjusted based on transmission capability of the specific receiver device.

19. The method of claim 1, further comprising:

multiplexing pilot symbols with the modulation symbols for the one or more data streams.

20. The method of claim 1, wherein the pilot symbols are multiplexed with the modulation symbols using frequency division multiplexing (FDM).

21. A method for processing data for transmission in a multiple-input multiple-output (MIMO) communication system that utilizes orthogonal frequency division multiplexing (OFDM), comprising:

selecting a particular diversity transmission mode from among a plurality of possible transmission modes to use for each of one or more data streams, wherein each selected diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof by using frequency diversity, Walsh transmit diversity, space time transmit diversity (STTD), or any combination thereof;

coding and modulating each data stream based on coding and modulation schemes selected for the data stream to provide modulation symbols; and

processing the modulation symbols for each data stream based on the selected diversity transmission mode to provide transmit symbols for transmission over a plurality of transmit antennas.

22. The method of claim 21, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode, a Walsh diversity transmission mode, and a STTD transmission mode.

23. The method of claim 22, wherein the plurality of possible transmission modes further includes a Walsh-STTD transmission mode.

24. A method for processing data for transmission in a multiple-input multiple-output (MIMO) communication system that utilizes orthogonal frequency division multiplexing (OFDM), comprising:

coding and modulating data to provide one or more substreams of modulation symbols for each of a plurality of OFDM subbands; and

for each of the plurality of OFDM subbands, processing the modulation symbols in the one or more substreams for the OFDM subband to provide transmit symbols, wherein the modulation symbols are processed in accordance with a particular diversity processing scheme selected for the OFDM subband to provide diversity in time, frequency, space, or a combination thereof.

25. The method of claim 24, wherein the selected diversity processing scheme for at least one OFDM subband is a space time transmit diversity (STTD) scheme.

26. The method of claim 24, wherein the selected diversity processing scheme for at least one OFDM subband is a Walsh transmit diversity scheme.

27. The method of claim 24, wherein the selected diversity processing scheme for at least one OFDM subband is a Walsh-space time transmit diversity (Walsh-STTD) scheme.

28. A method for processing a data transmission at a receiver of a wireless communication system, comprising:

determining a particular diversity transmission mode used for each of one or more data streams to be recovered from a received data transmission, wherein the diversity transmission mode used for each data stream is selected from among a plurality of possible transmission modes, and wherein each diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof; and

processing received symbols for each data stream based on the diversity transmission mode used for the data stream to provide recovered symbols that are estimates of modulation symbols transmitted from a transmitter for the data stream.

29. The method of claim 28, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode, a Walsh diversity transmission mode, and a space time transmit diversity (STTD) transmission mode.

30. The method of claim 29, wherein the plurality of possible transmission modes further includes a Walsh-STTD transmission mode.

31. The method of claim 29, wherein the plurality of possible transmission modes further includes a frequency-STTD transmission mode.

32. The method of claim 28, further comprising:

demodulating and decoding the recovered symbols for each data stream to provide decoded data.

33. A memory communicatively coupled to a digital signal processing device (DSPD) capable of interpreting digital information to:

select a particular diversity transmission mode from among a plurality of possible transmission modes to use for each of one or more data streams, wherein each selected diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof;

code and modulate each data stream based on coding and modulation schemes selected for the data stream to provide modulation symbols; and

process the modulation symbols for each data stream based on the selected diversity transmission mode to provide transmit symbols for transmission over one or more transmit antennas.

34. A transmitter unit in a wireless communication system, comprising:

a controller operative to select a particular diversity transmission mode from among a plurality of possible transmission modes to use for each of one or more data streams, wherein each selected diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof;

a TX data processor operative to code and modulate each data stream based on coding and modulation schemes selected for the data stream to provide modulation symbols; and

a transmit processor operative to process the modulation symbols for each data stream based on the selected diversity transmission mode to provide transmit symbols for transmission over one or more transmit antennas.

35. The transmitter unit of claim 34, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode, a Walsh diversity transmission mode, and a space time transmit diversity (STTD) transmission mode.

36. The transmitter unit of claim 35, wherein the plurality of possible transmission modes further includes a Walsh-STTD transmission mode.

37. The transmitter unit of claim 35, wherein the plurality of possible transmission modes further includes a frequency-STTD transmission mode.

38. The transmitter unit of claim 34, wherein the wireless communication system is a multiple-input multiple-output (MIMO) communication system that utilizes orthogonal frequency division multiplexing (OFDM).

39. The transmitter unit of claim 38, wherein the transmit processor is further operative to OFDM modulate the transmit symbols for the one or more data streams to provide a stream of transmission symbols for each transmit antenna used for data transmission.

40. An access point comprising the transmitter unit of claim 34.

41. A terminal comprising the transmitter unit of claim 34.

42. An apparatus in a multiple-input multiple-output (MIMO) communication system, comprising:

means for selecting a particular diversity transmission mode from among a plurality of possible transmission modes to use for each of one or more data streams, wherein each selected diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof;

means for coding and modulating each data stream based on coding and modulation schemes selected for the data stream to provide modulation symbols; and

means for processing the modulation symbols for each data stream based on the selected diversity transmission mode to provide transmit symbols for transmission over one or more transmit antennas.

43. The apparatus of claim 42, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode, a Walsh diversity transmission mode, and a space time transmit diversity (STTD) transmission mode.

44. A receiver unit in a wireless communication system, comprising:

a controller operative to determine a particular diversity transmission mode used for each of one or more data streams to be recovered from a received data transmission, wherein the diversity transmission mode used for each data stream is selected from among a plurality of possible transmission modes, and wherein each diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof; and

a receive processor operative to process received symbols for each data stream based on the diversity transmission mode used for the data stream to provide recovered symbols that are estimates of modulation symbols transmitted from a transmitter for the data stream.

45. The receiver unit of claim 44, further comprising:

a receive data processor operative to demodulate and decode the recovered symbols for each data stream to provide decoded data.

46. The receiver unit of claim 44, wherein the plurality of possible transmission modes includes a frequency diversity transmission mode, a Walsh

diversity transmission mode, and a space time transmit diversity (STTD) transmission mode.

47. An access point comprising the receiver unit of claim 44.

48. A terminal comprising the receiver unit of claim 44.

49. A receiver apparatus in a wireless communication system, comprising:

means for determining a particular diversity transmission mode used for each of one or more data streams to be recovered from a received data transmission, wherein the diversity transmission mode used for each data stream is selected from among a plurality of possible transmission modes, and wherein each diversity transmission mode redundantly transmits data over time, frequency, space, or a combination thereof; and

means for processing received symbols for each data stream based on the diversity transmission mode used for the data stream to provide recovered symbols that are estimates of modulation symbols transmitted from a transmitter for the data stream.

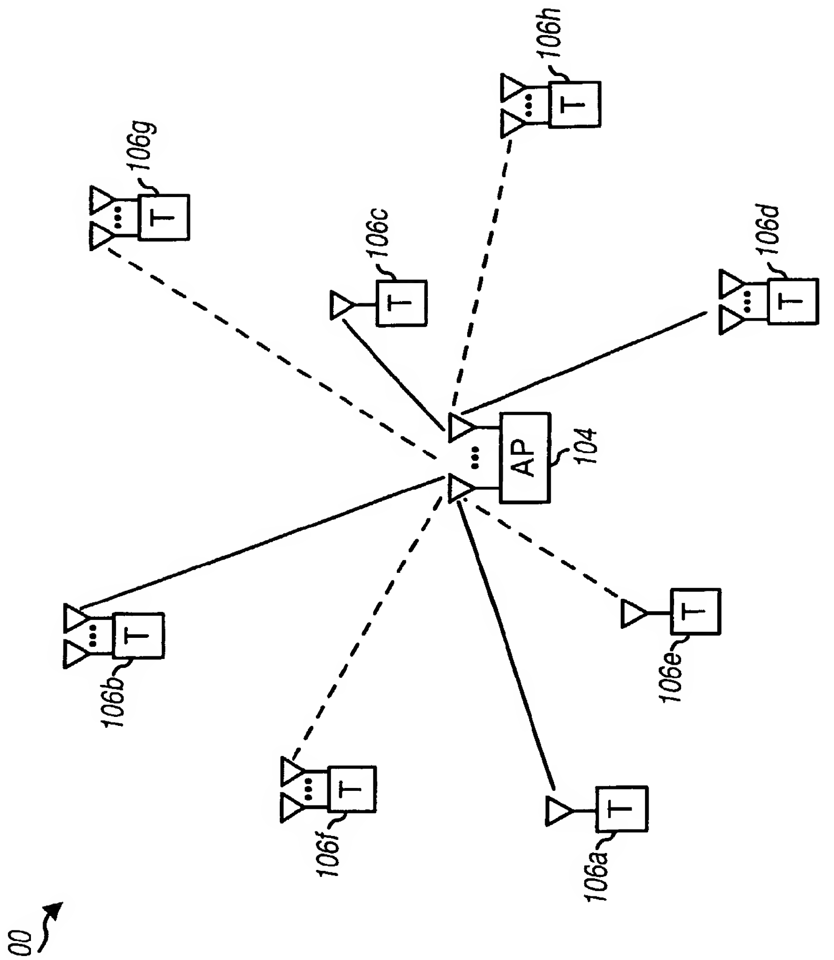


FIG. 1

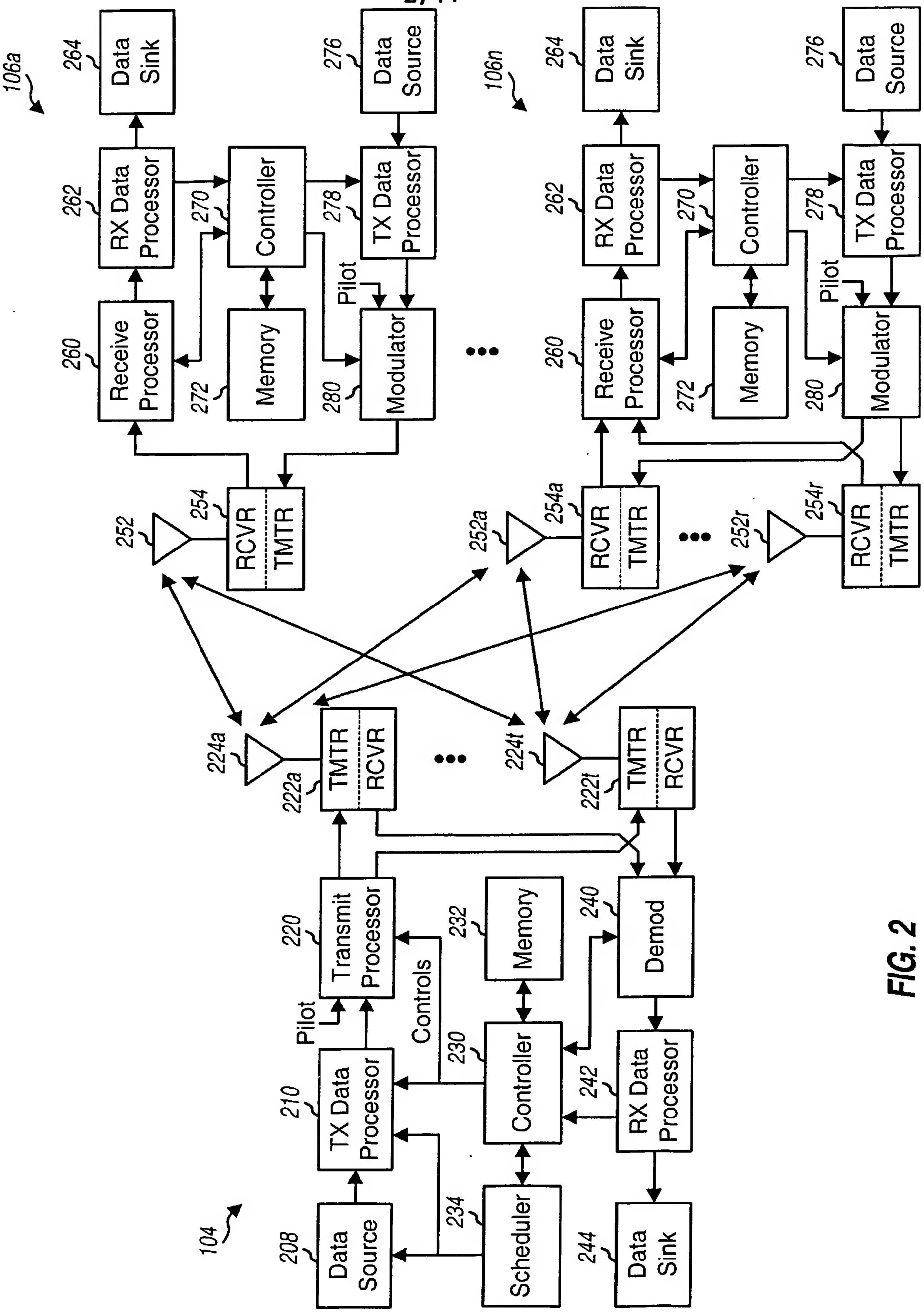

104
208 Data Source
210 TX Data Processor
220 Transmit Processor
Pilot
Controls
230 Controller
232 Memory
234 Scheduler
240 Demod
242 RX Data Processor
244 Data Sink
222a TMTR RCVR
224a
222t TMTR RCVR
224t
106a
252
254 RCVR TMTR
260 Receive Processor
262 RX Data Processor
264 Data Sink
270 Controller
272 Memory
276 Data Source
278 TX Data Processor
280 Modulator
Pilot
106n
252a
254a RCVR TMTR
252r
254r RCVR TMTR
260 Receive Processor
262 RX Data Processor
264 Data Sink
270 Controller
272 Memory
276 Data Source
278 TX Data Processor
280 Modulator
Pilot

FIG. 2

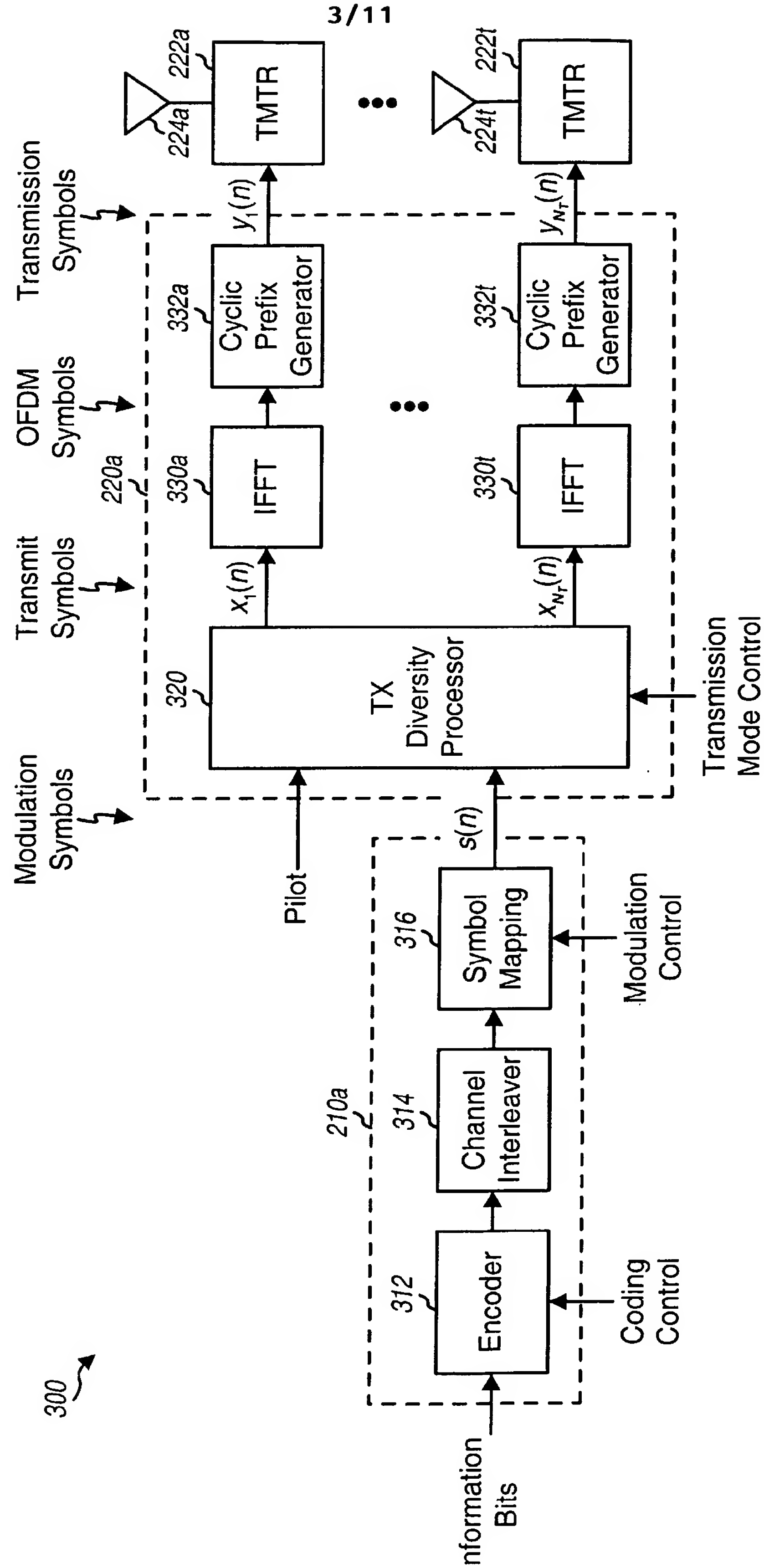

300
Information Bits
210a
312
Encoder
Coding Control
314
Channel Interleaver
316
Symbol Mapping
Modulation Control
s(n)
Pilot
Modulation Symbols
220a
320
TX Diversity Processor
Transmission Mode Control
Transmit Symbols
x1(n)
xNT(n)
330a
IFFT
330t
IFFT
OFDM Symbols
332a
Cyclic Prefix Generator
332t
Cyclic Prefix Generator
Transmission Symbols
y1(n)
yNT(n)
222a
TMTR
224a
222t
TMTR
224t

FIG. 3

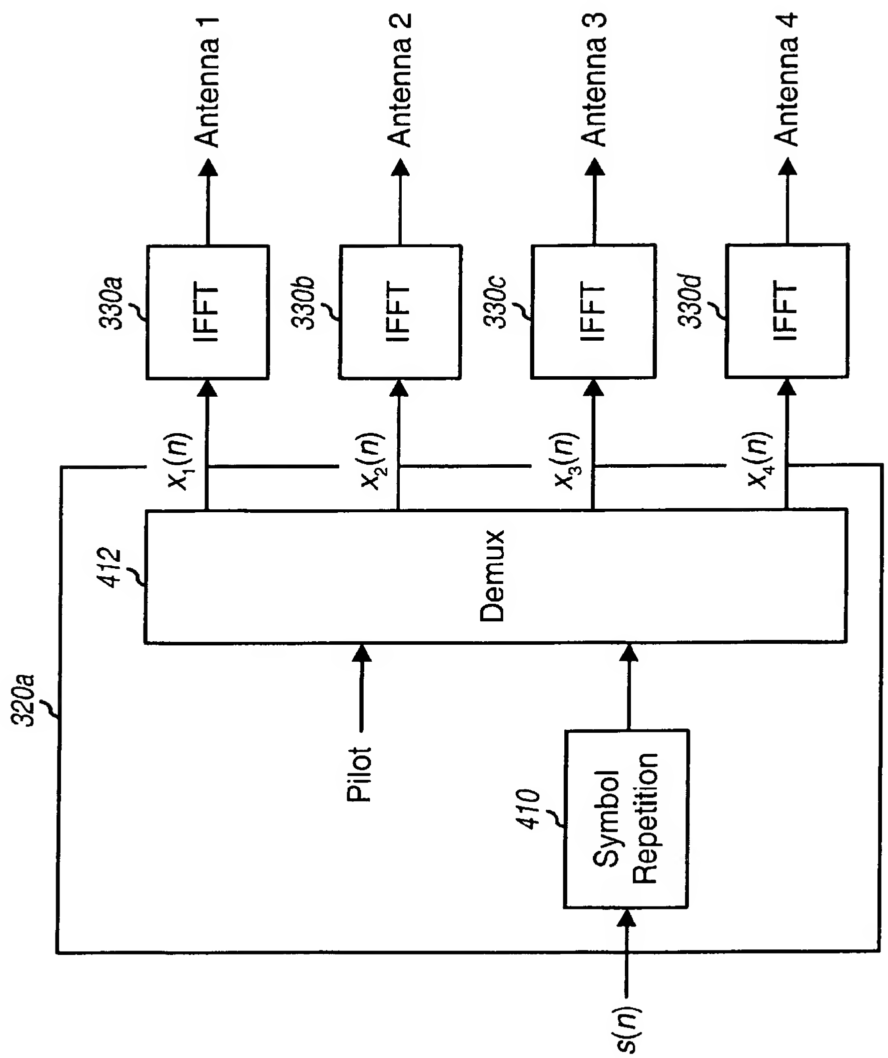

Antenna 1
Antenna 2
Antenna 3
Antenna 4
330a
IFFT
330b
IFFT
330c
IFFT
330d
IFFT
$x_1(n)$
$x_2(n)$
$x_3(n)$
$x_4(n)$
412
Demux
320a
Pilot
410
Symbol Repetition
$s(n)$

FIG. 4

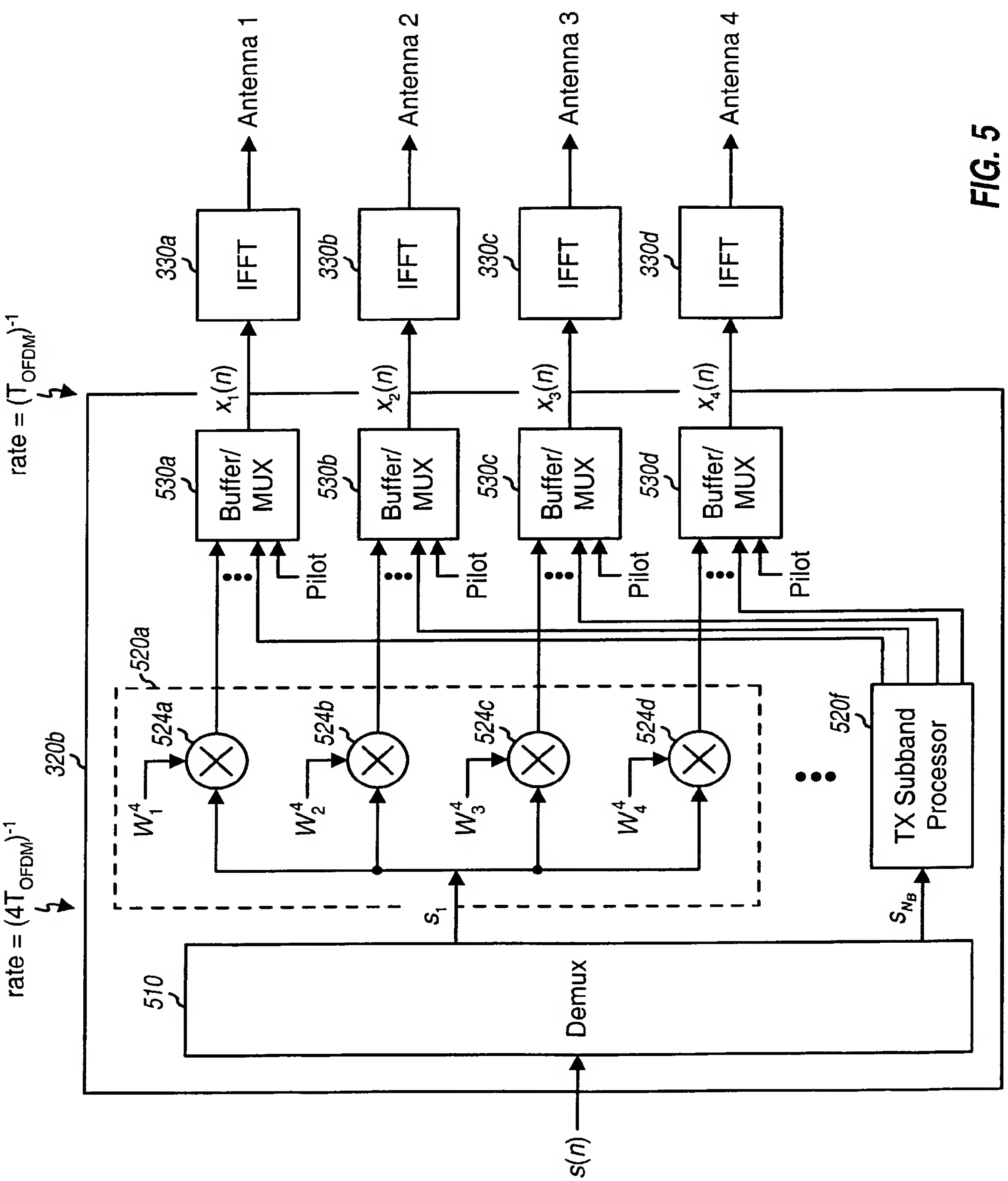
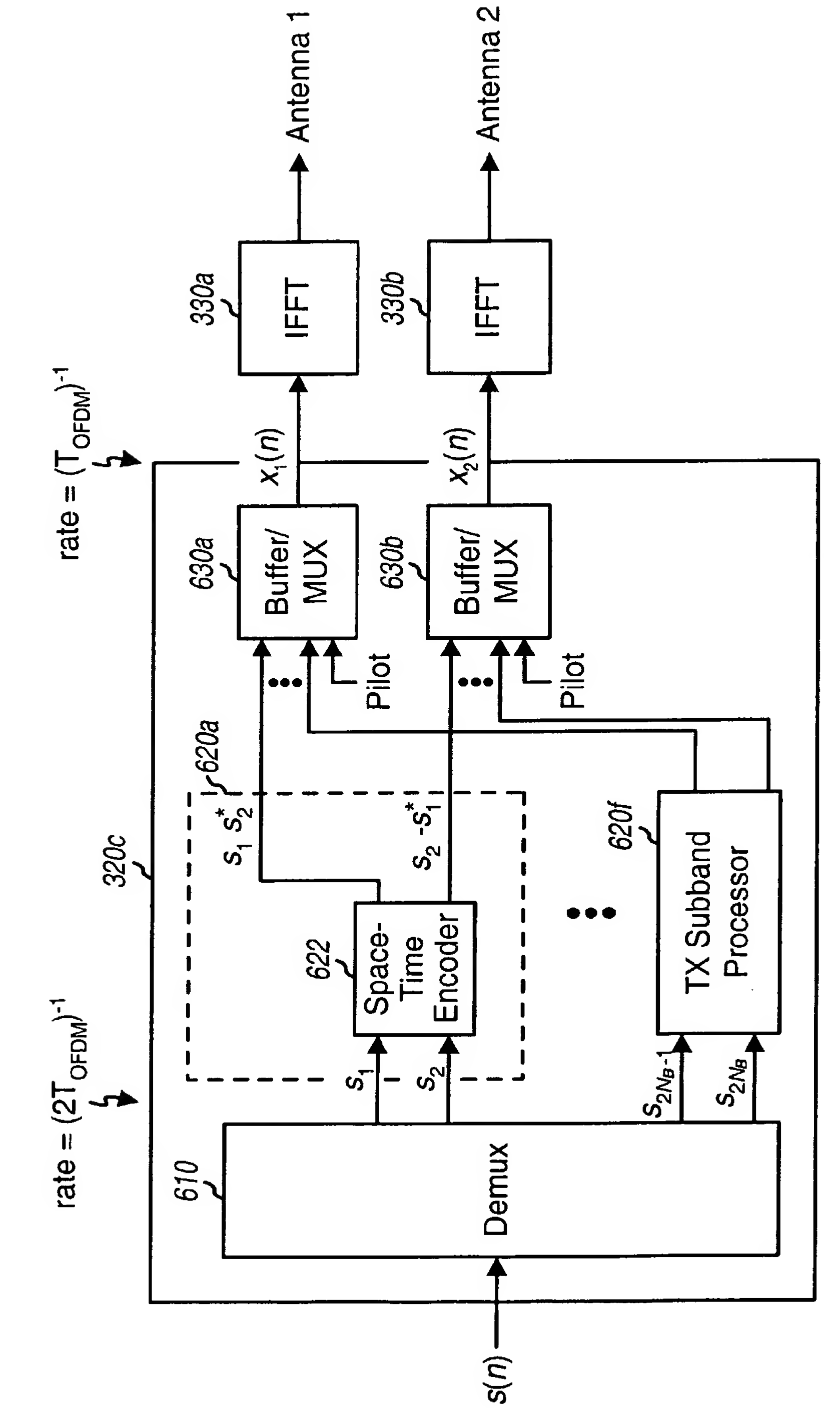

rate = (4T_OFDM)^-1
rate = (T_OFDM)^-1
320b
510
Demux
s(n)
s_1
s_NB
520a
524a
524b
524c
524d
W_1^4
W_2^4
W_3^4
W_4^4
520f
TX Subband Processor
Pilot
Pilot
Pilot
Pilot
530a
530b
530c
530d
Buffer/ MUX
Buffer/ MUX
Buffer/ MUX
Buffer/ MUX
x_1(n)
x_2(n)
x_3(n)
x_4(n)
330a
330b
330c
330d
IFFT
IFFT
IFFT
IFFT
Antenna 1
Antenna 2
Antenna 3
Antenna 4

FIG. 5



Antenna 1
Antenna 2
330a
IFFT
330b
IFFT
rate = $(T_{OFDM})^{-1}$
$x_1(n)$
$x_2(n)$
630a
Buffer/ MUX
630b
Buffer/ MUX
Pilot
Pilot
620a
s_1 s_2^*
s_2 $-s_1^*$
320c
622
Space-Time Encoder
620f
TX Subband Processor
rate = $(2T_{OFDM})^{-1}$
s_1
s_2
s_{2N_B-1}
s_{2N_B}
610
Demux
$s(n)$

FIG. 6

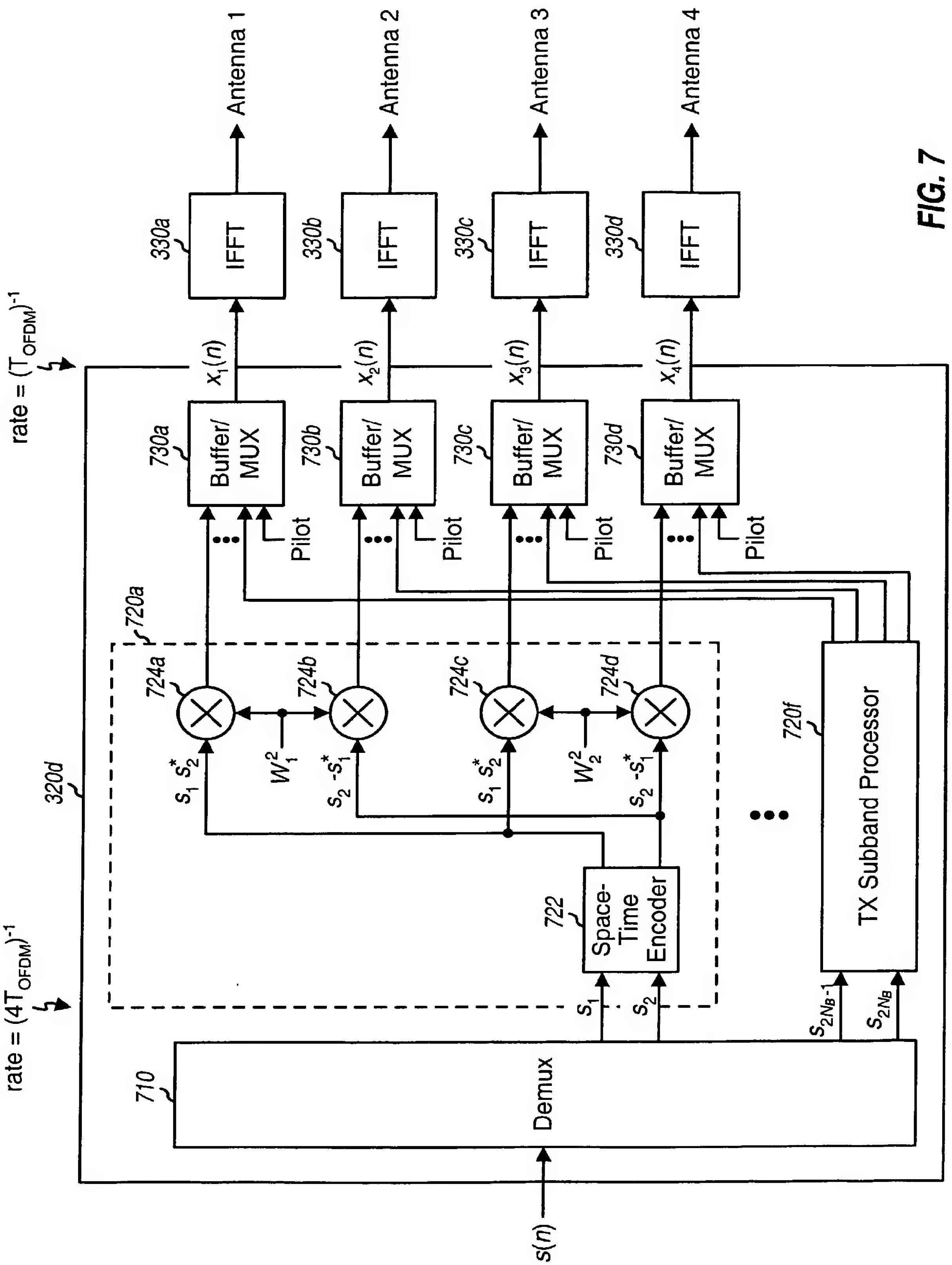

rate = $(4T_{OFDM})^{-1}$
rate = $(T_{OFDM})^{-1}$
320d
710
Demux
$s(n)$
s_1
s_2
s_{2N_B-1}
s_{2N_B}
720a
722
Space-Time Encoder
$s_1\ s_2^*$
$s_2\ -s_1^*$
W_1^2
W_2^2
724a
724b
724c
724d
720f
TX Subband Processor
Pilot
730a
730b
730c
730d
Buffer/ MUX
$x_1(n)$
$x_2(n)$
$x_3(n)$
$x_4(n)$
330a
330b
330c
330d
IFFT
Antenna 1
Antenna 2
Antenna 3
Antenna 4

FIG. 7

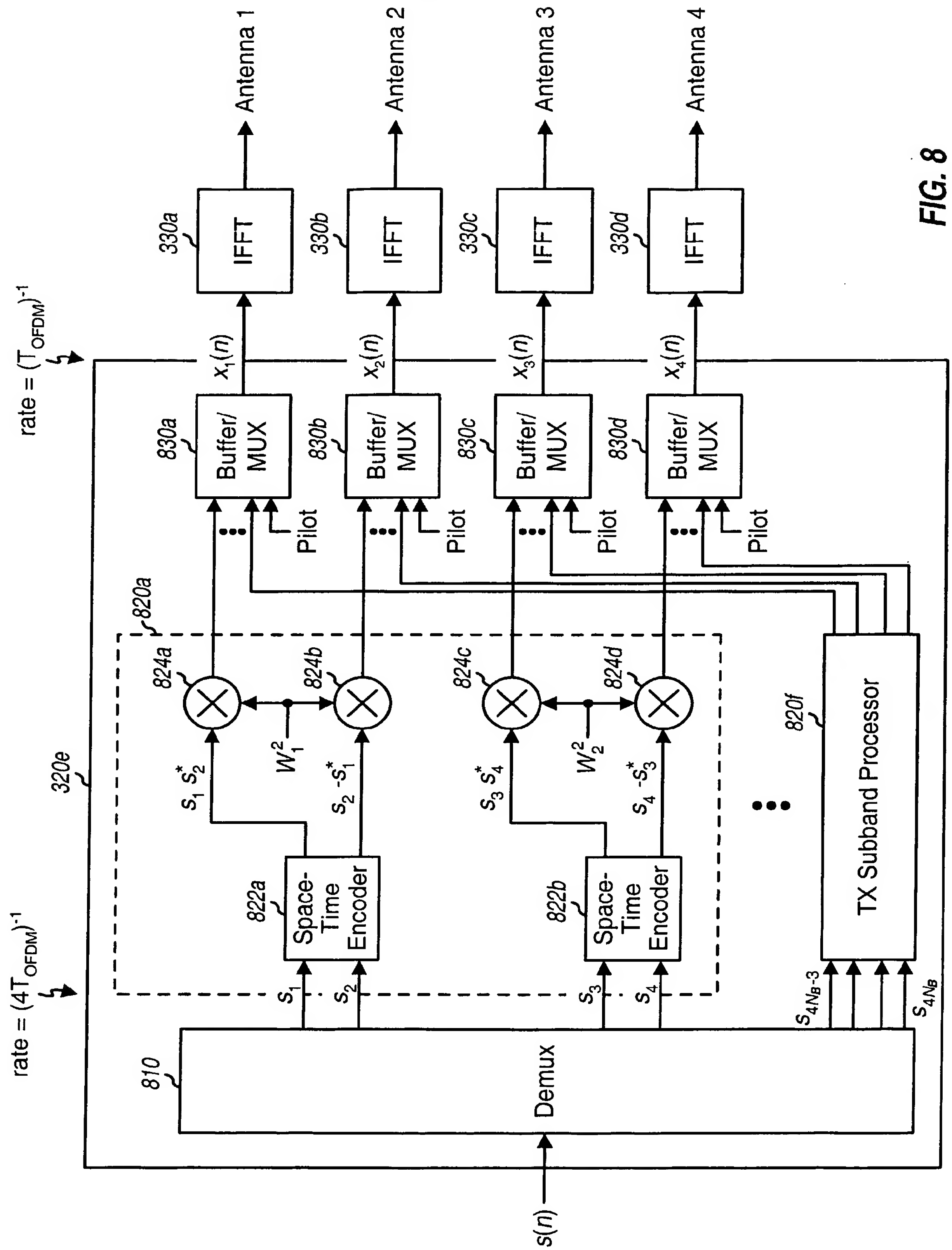

rate = $(4T_{OFDM})^{-1}$
rate = $(T_{OFDM})^{-1}$
320e
810
Demux
s(n)
820a
822a
Space-Time Encoder
822b
Space-Time Encoder
s_1
s_2
s_3
s_4
$s_1\ s_2^*$
$s_2\ -s_1^*$
$s_3\ s_4^*$
$s_4\ -s_3^*$
W_1^2
W_2^2
824a
824b
824c
824d
820f
TX Subband Processor
s_{4N_B-3}
s_{4N_B}
Pilot
830a
830b
830c
830d
Buffer/ MUX
$x_1(n)$
$x_2(n)$
$x_3(n)$
$x_4(n)$
330a
330b
330c
330d
IFFT
Antenna 1
Antenna 2
Antenna 3
Antenna 4

FIG. 8

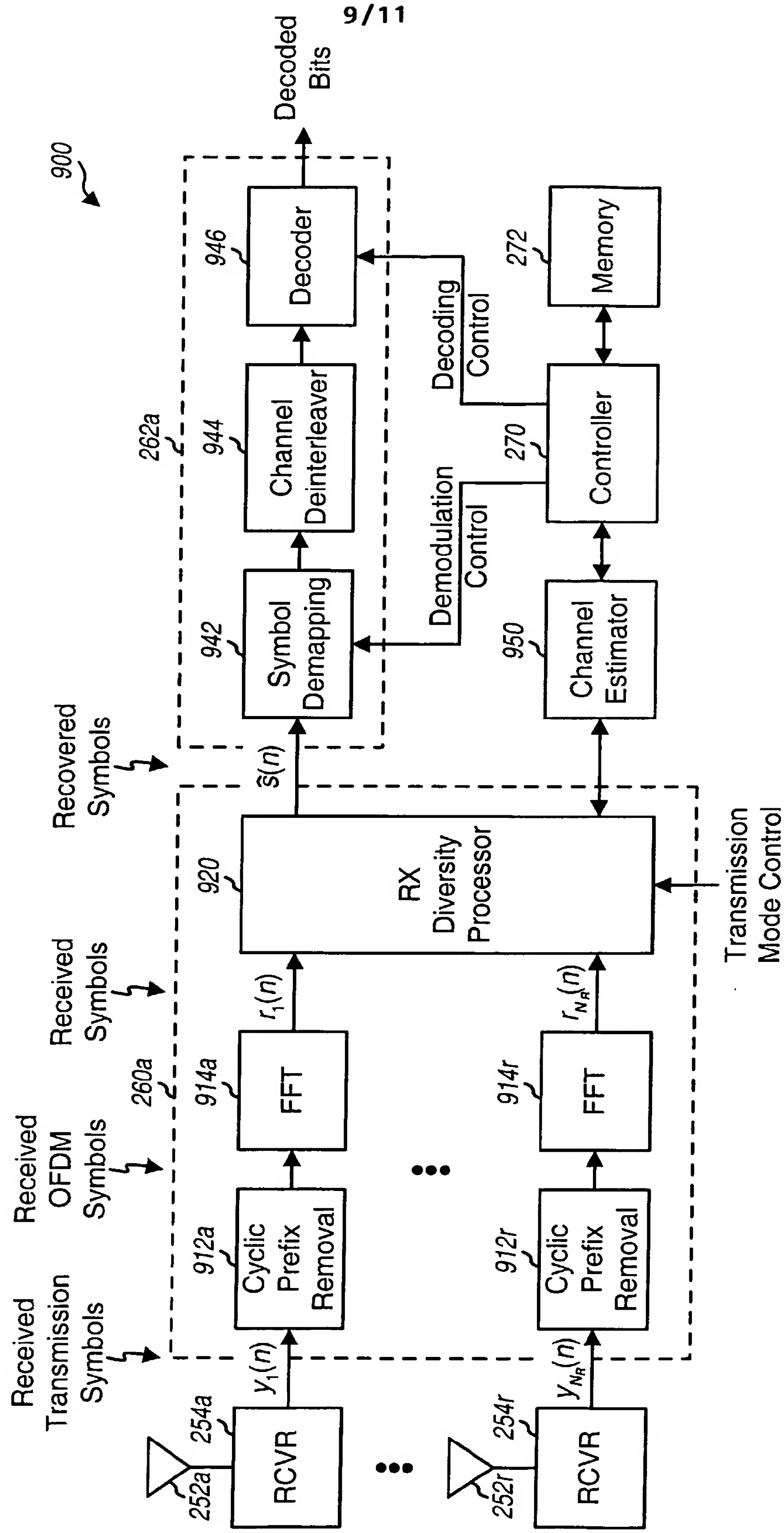

900
Received Transmission Symbols
Received OFDM Symbols
Received Symbols
Recovered Symbols
252a
254a
RCVR
252r
254r
RCVR
$y_1(n)$
$y_{N_R}(n)$
260a
912a
Cyclic Prefix Removal
912r
Cyclic Prefix Removal
914a
FFT
914r
FFT
$r_1(n)$
$r_{N_R}(n)$
920
RX Diversity Processor
Transmission Mode Control
$\hat{s}(n)$
262a
942
Symbol Demapping
944
Channel Deinterleaver
946
Decoder
Decoded Bits
Demodulation Control
Decoding Control
950
Channel Estimator
270
Controller
272
Memory

FIG. 9

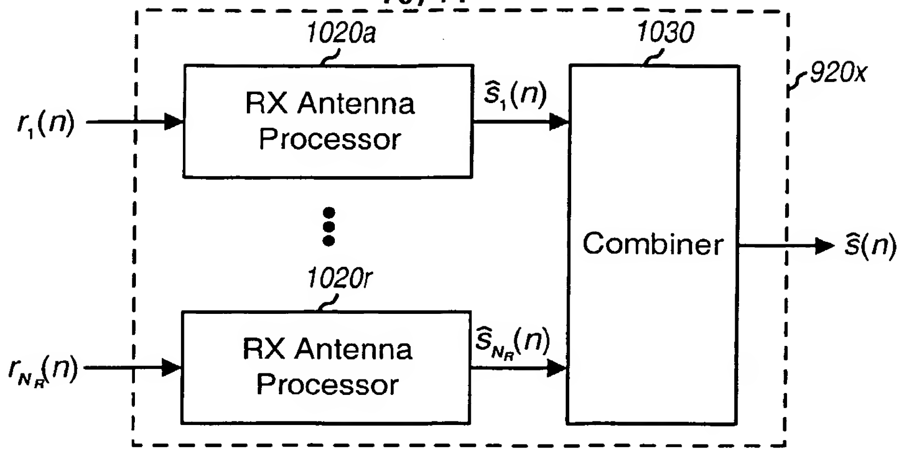

1020a
1030
920x
$r_1(n)$
RX Antenna Processor
$\hat{s}_1(n)$
Combiner
$\hat{s}(n)$
1020r
$r_{N_R}(n)$
RX Antenna Processor
$\hat{s}_{N_R}(n)$

FIG. 10

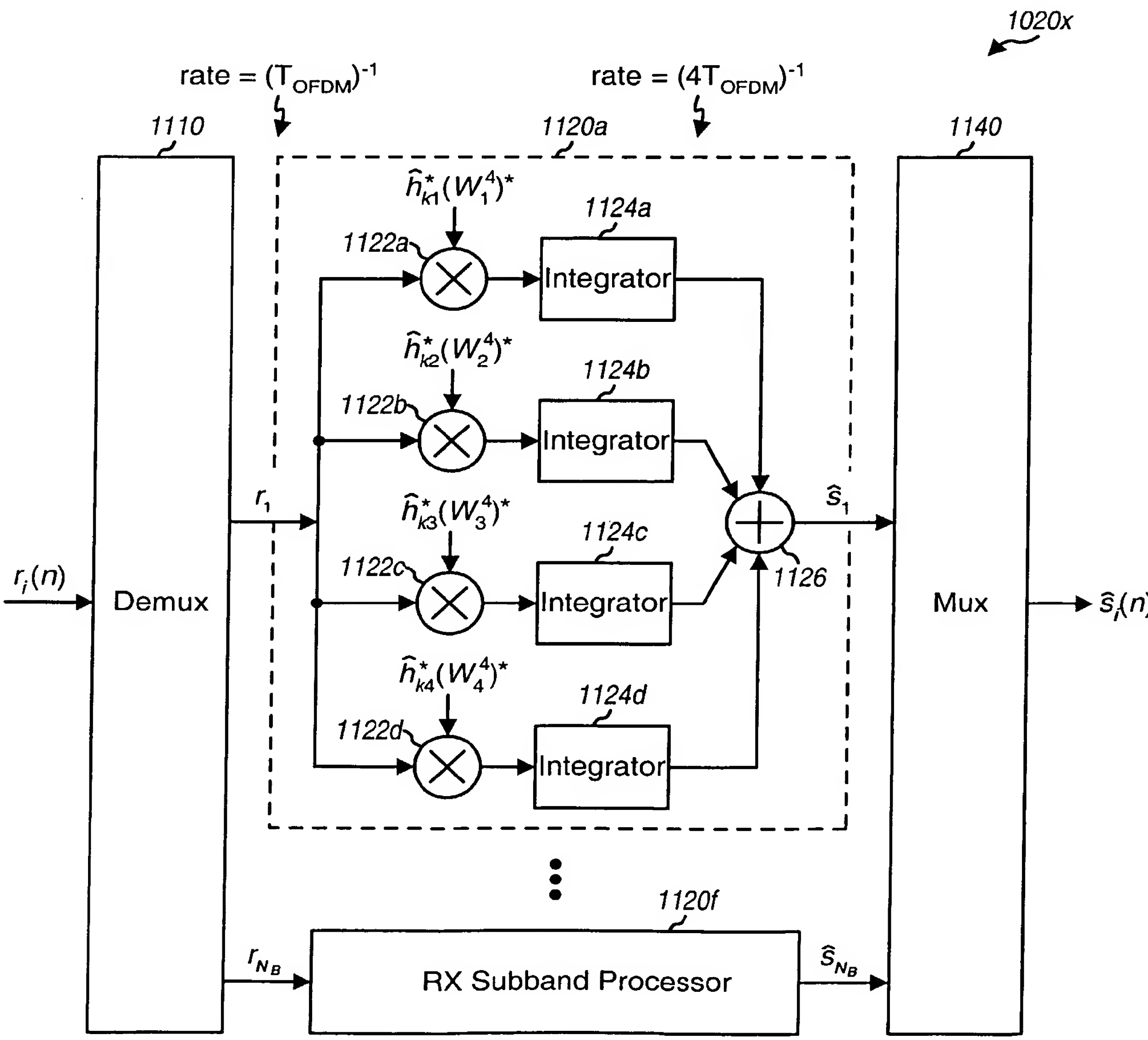

1020x
rate = $(T_{OFDM})^{-1}$
rate = $(4T_{OFDM})^{-1}$
1110
1120a
1140
$\hat{h}^*_{k1}(W^4_1)^*$
1124a
1122a
Integrator
$\hat{h}^*_{k2}(W^4_2)^*$
1124b
1122b
Integrator
r_1
$\hat{s}_1$
$\hat{h}^*_{k3}(W^4_3)^*$
1124c
1122c
Integrator
1126
$r_i(n)$
Demux
Mux
$\hat{s}_i(n)$
$\hat{h}^*_{k4}(W^4_4)^*$
1124d
1122d
Integrator
1120f
r_{N_B}
RX Subband Processor
$\hat{s}_{N_B}$

FIG. 11

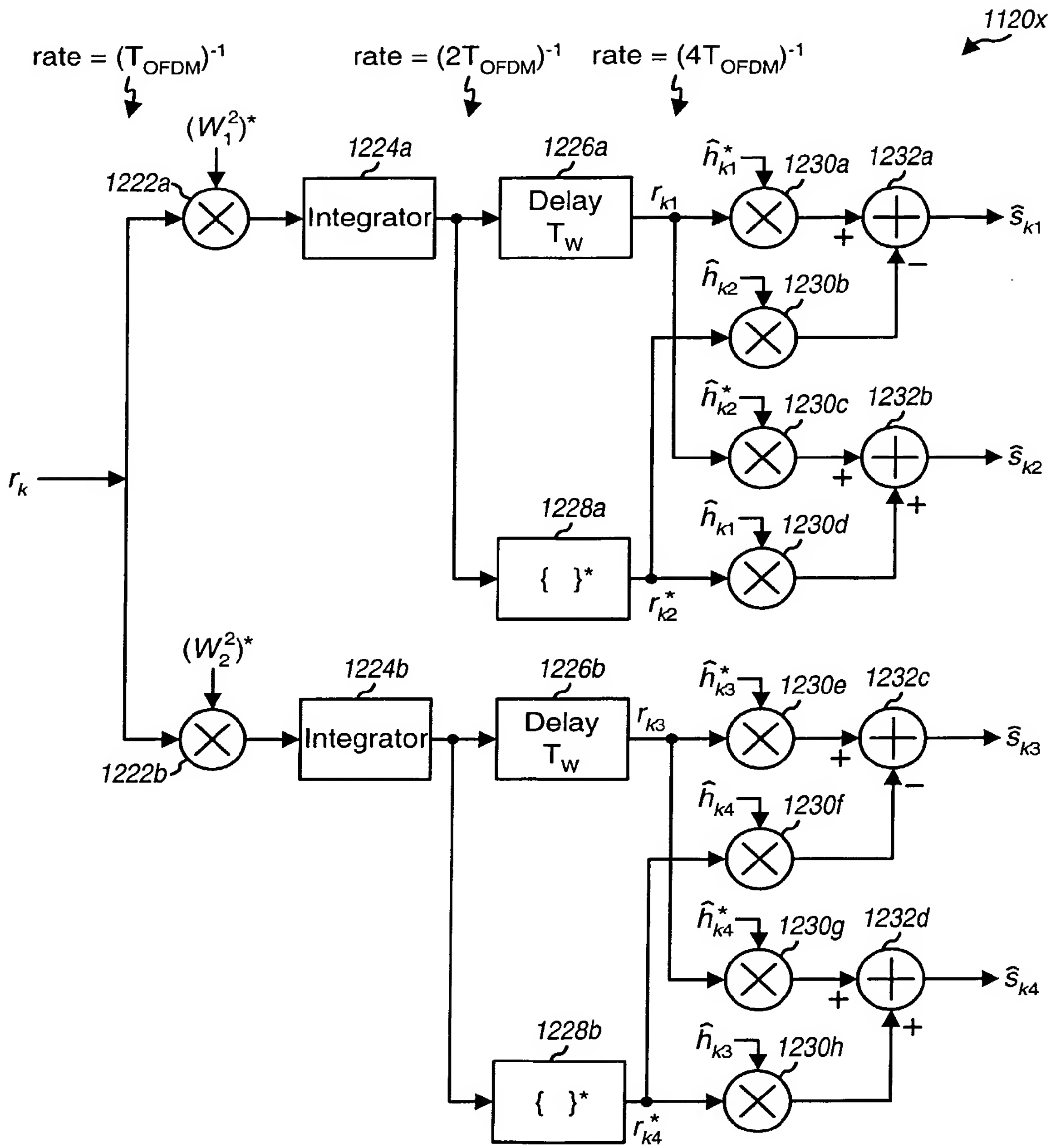

1120x
rate = $(T_{OFDM})^{-1}$
rate = $(2T_{OFDM})^{-1}$
rate = $(4T_{OFDM})^{-1}$
$(W_1^2)^*$
1222a
1224a
Integrator
1226a
Delay T_W
r_{k1}
$\hat{h}_{k1}^*$
1230a
1232a
$\hat{s}_{k1}$
$\hat{h}_{k2}$
1230b
$\hat{h}_{k2}^*$
1230c
1232b
$\hat{s}_{k2}$
r_k
1228a
$\{\ \}^*$
$\hat{h}_{k1}$
1230d
r_{k2}^*
$(W_2^2)^*$
1222b
1224b
Integrator
1226b
Delay T_W
r_{k3}
$\hat{h}_{k3}^*$
1230e
1232c
$\hat{s}_{k3}$
$\hat{h}_{k4}$
1230f
$\hat{h}_{k4}^*$
1230g
1232d
$\hat{s}_{k4}$
1228b
$\{\ \}^*$
$\hat{h}_{k3}$
1230h
r_{k4}^*

FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/19466

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/04 H04L27/26 H04L1/06 H04B7/06 H04J11/00
H04L1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H04L H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01 76110 A (QUALCOMM INC) 11 October 2001 (2001-10-11)	1,2, 11-21, 24,28, 32-34, 38-42, 44,45, 47-49
Y		3-10,22, 23, 25-27, 29-31, 35-37, 43,46
	page 8, line 24 -page 9, line 21 page 12, line 5 -page 13, line 11 page 18, line 21 -page 19, line 13 page 27, line 18 -page 28, line 5 page 32, line 22 - line 29; figure 3 claims 1,8-10	
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 October 2003	04/11/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sieben, S

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Internati ›plication No
PCT/US 03/19466

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 182 799 A (LUCENT TECHNOLOGIES INC) 27 February 2002 (2002-02-27) paragraph ‘0024! paragraph ‘0048!	3-10,22, 23, 25-27, 29-31, 35-37, 43,46
A	EP 1 158 716 A (AT & T CORP) 28 November 2001 (2001-11-28) paragraph ‘0009! paragraph ‘0014! - paragraph ‘0016!; figure 4	1-49

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 03/19466

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 0176110	A	11-10-2001	US	6473467	B1	29-10-2002
			AU	4592101	A	15-10-2001
			CA	2402152	A1	11-10-2001
			EP	1269665	A2	02-01-2003
			NO	20024634	A	20-11-2002
			TW	508922	B	01-11-2002
			WO	0176110	A2	11-10-2001
EP 1182799	A	27-02-2002	BR	0103361	A	23-04-2002
			CA	2351844	A1	22-02-2002
			CN	1339885	A	13-03-2002
			EP	1182799	A2	27-02-2002
			JP	2002135232	A	10-05-2002
EP 1158716	A	28-11-2001	US	2001053143	A1	20-12-2001
			CN	1325198	A	05-12-2001
			EP	1158716	A2	28-11-2001
			JP	2002044051	A	08-02-2002
			TW	510103	B	11-11-2002